Kansas Geological Survey

High Plains Aquifer Calibration Monitoring Well Program: Year 1 Progress Report on Well Installation and Aquifer Response

by

D.P. Young, R.W. Buddemeier, D.O. Whittemore, and E. Reboulet

Kansas Geological Survey Open-file Report 2007-30
2007

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Introduction

The calibration monitoring (index) well program is a pilot study of an improved approach to measuring hydrologic responses at the local level. The study is being funded by the Kansas Water Office (KWO). It is being undertaken because of the KWO's interest in and responsibility for long-term planning of the Ogallala-High Plains aquifer in western Kansas. The program is expected to make a significant contribution to understanding the aquifer dynamics, and ultimately, improving the long-term management approach.

The Kansas Water Plan has outlined a goal for management of the Ogallala-High Plains aquifer by aquifer subunit. For the calibration monitoring well program, the KWO requested one well in each of the three western Kansas groundwater management districts (GMDs) to support their efforts to define aquifer subunits and long-term management approaches. The hypotheses to be tested by this program are that

1. Properly designed, sited, and measured wells can yield water-level measurements that, supported by supplemental measurements in other wells in the vicinity, are sufficiently accurate and representative of local water-table behavior to use in intensive management programs; and
2. Consistent deviations in water levels from the behavior of a calibration well indicate aquifer heterogeneity; such results can be interpreted to refine subunit definitions and characteristics or to inform the interpretation of water-table responses over larger/other areas.

One newly constructed well in each of the western Kansas GMDs will be monitored continuously over a period of ~5 years to address the following questions:

- Where, how, and at what level of confidence can high-quality measurements from a specifically designed, sited, and constructed monitoring well be combined with supplemental measurements of wells of opportunity to characterize water-level behavior over an area on the scale of an aquifer subunit?

- What can these measurements tell us about the results of the annual water-level program, and about possible opportunities for improvement?

- What can we learn about widely occurring but poorly characterized deviations from the "homogeneous aquifer" assumptions (e.g., fringe effects, confinement, recharge variation, variation in practical saturated thickness, etc.)?

A subsidiary goal is to directly examine issues and areas of particular interest to the GMDs and the Division of Water Resources, Kansas Department of Agriculture (DWR). A document describing the rationale and conceptual framework for the program in more detail is included in Appendix A.

The selected sites make the maximum use of additional data sources, local interest, and relevance to other goals and programs. They address a variety of ground-water settings that are both individually and generally important, and will contribute to generalized knowledge as well as specific local information.

Installations

Three index wells have been installed in the Ogallala-High Plains aquifer, one in each of the three western Kansas GMDs. The sites are located in Haskell (GMD3), Scott (GMD1), and Thomas (GMD4) counties (Figure 1). Each site is instrumented with a pressure transducer and telemetry system for real-time water-level data transfer. Figure 2 is a photograph of a typical installation. Elevations of the wells were surveyed by a licensed land surveyor, as were elevations of a number of wells in the annual water-level measurement network in the area of the index wells and 20 wells that the DWR is monitoring near the Haskell County index well (discussed in the results and discussion section).

A number of factors went into site selection. Considerations included: proximity to pumping wells and annual water-level monitoring wells, saturated thickness, decline rates, and general lithology and hydrogeology (degree of homogeneity, degree of confinement). See Appendix A for information regarding the rationale.

Figures 3 and 4 illustrate the High Plains aquifer 2005 saturated thickness and change in saturated thickness since predevelopment, respectively. As illustrated in Figure 3, the Haskell County site area has the most saturated thickness remaining of the three well locations, however, there is a transition to less saturated thickness from southwest to northeast at this site. The Scott County site is located in the northern portion of the Scott-Finney bedrock depression, the only area with substantial ground-water reserves remaining in the eastern portion of GMD1. Of the three locations, the Thomas County site has the least saturated thickness remaining (in the 60 ft range). Figure 4 shows that all sites are in areas of substantial water-level declines relative to their respective districts.

Prior to final site selection, the lithology surrounding each site was characterized based on drillers logs (WWC5 forms). Figure 5 illustrates the subsurface lithology along a cross section in the area of each of the three index well sites. The lithologic information listed on the well logs is represented as five color-coded categories of materials as indicated in the legend. Lighter colors indicate the more permeable sediments and darker colors indicate the less permeable materials. The predevelopment and winter 2007 water levels based on measurements for the area are represented on each cross section. The screened interval for each index well is indicated by the two short horizontal lines at the bottom of the well labeled with an "*I*" above and below the colored column. Figure 6 displays the locations of the different wells in each of the cross sections shown in Figure 5. The lithology is discussed in the results and discussion section.

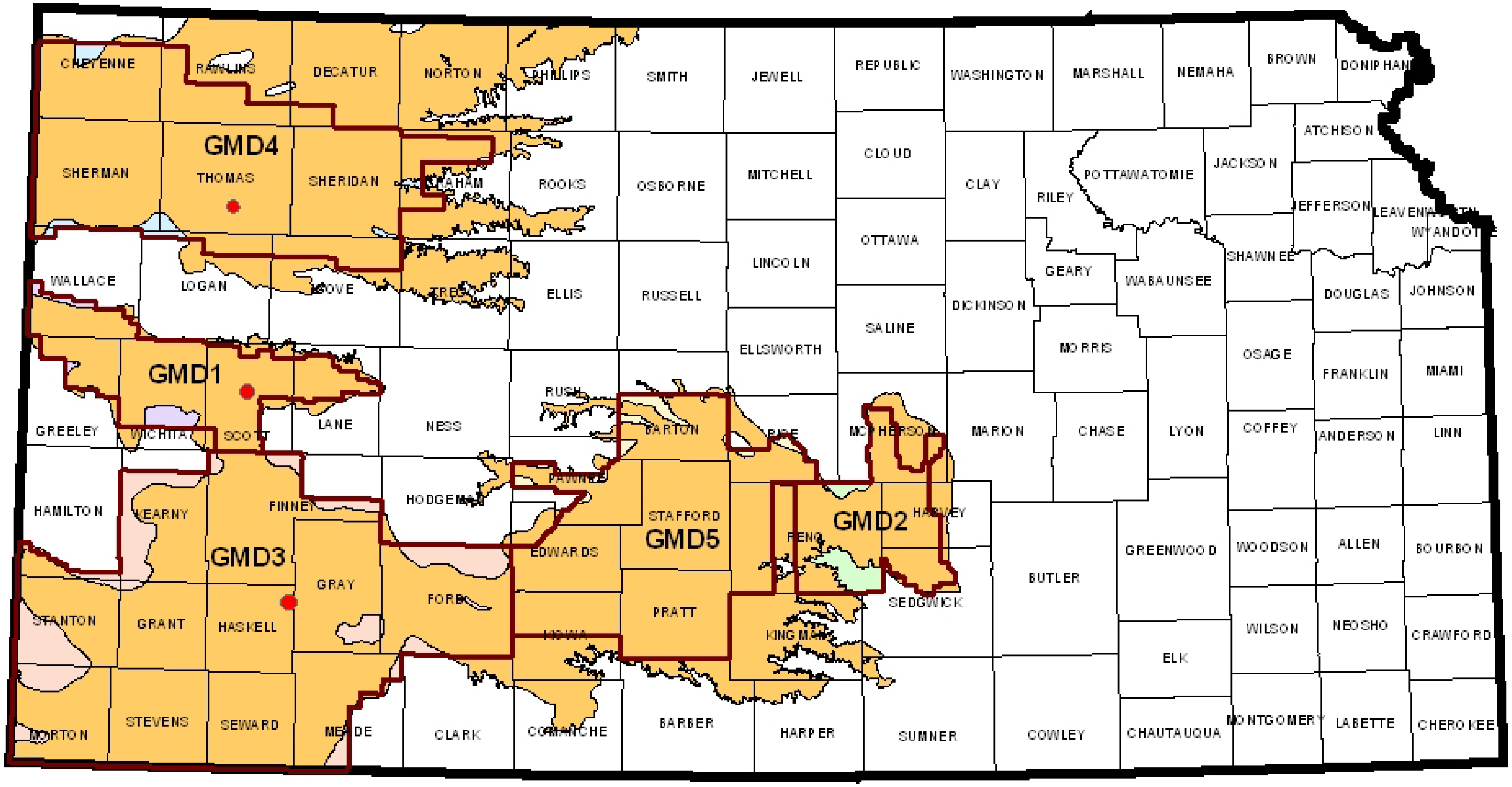


Figure 1. Map of Kansas showing extent of the High Plains aquifer, GMD and county boundaries, and locations of index wells (red dots) in Thomas, Scott, and Haskell counties.

Figure 2. Haskell County site during telemetry installation.

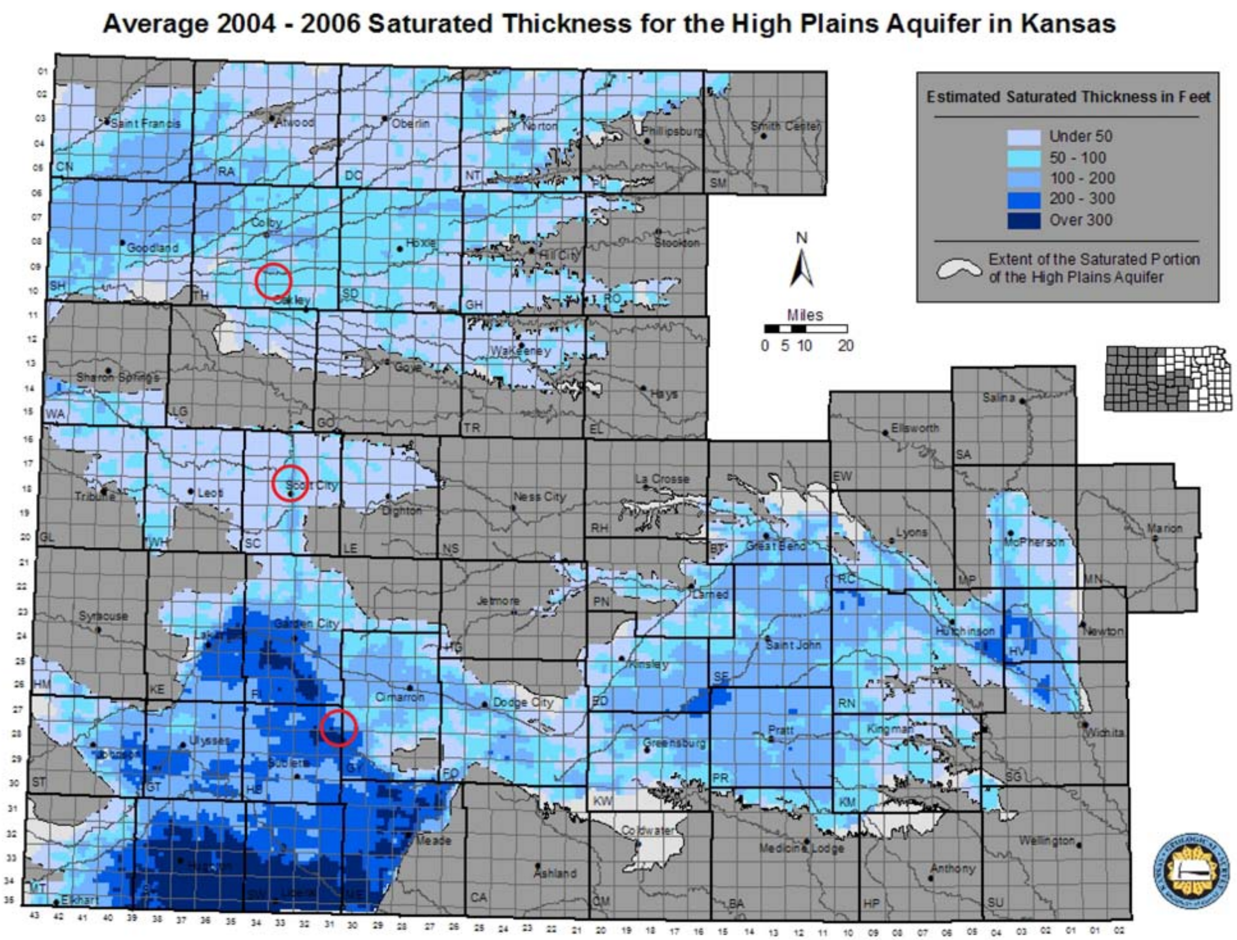


Figure 3. 2005 saturated thickness for the High Plains aquifer. The red circles indicate the index well locations.

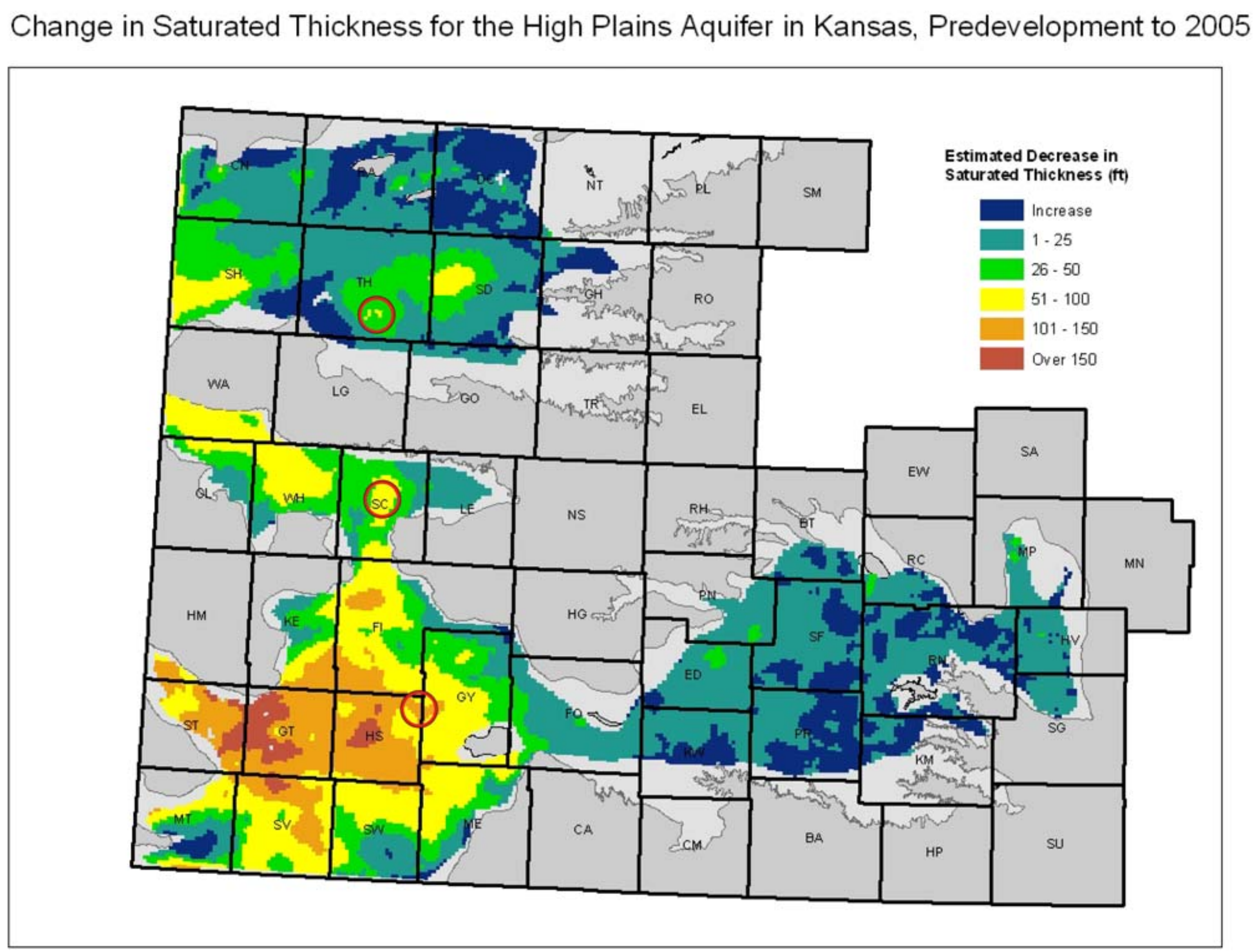


Figure 4. Change in saturated thickness for the High Plains aquifer, predevelopment to 2005. The red circles indicate the index well locations.

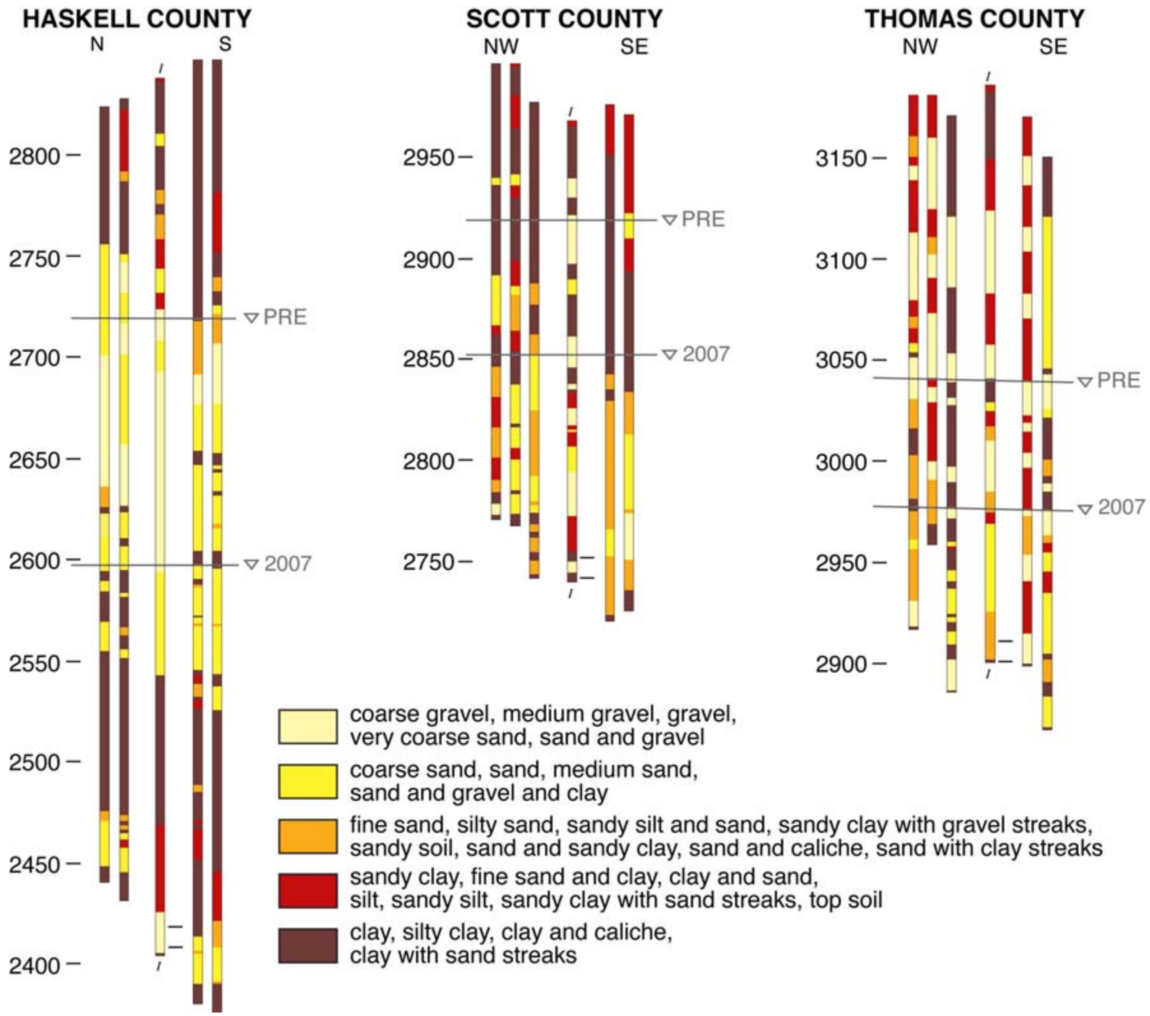


Figure 5. Lithologic cross sections for each well site. The labels PRE and 2007 represent predevelopment and 2007 water levels.

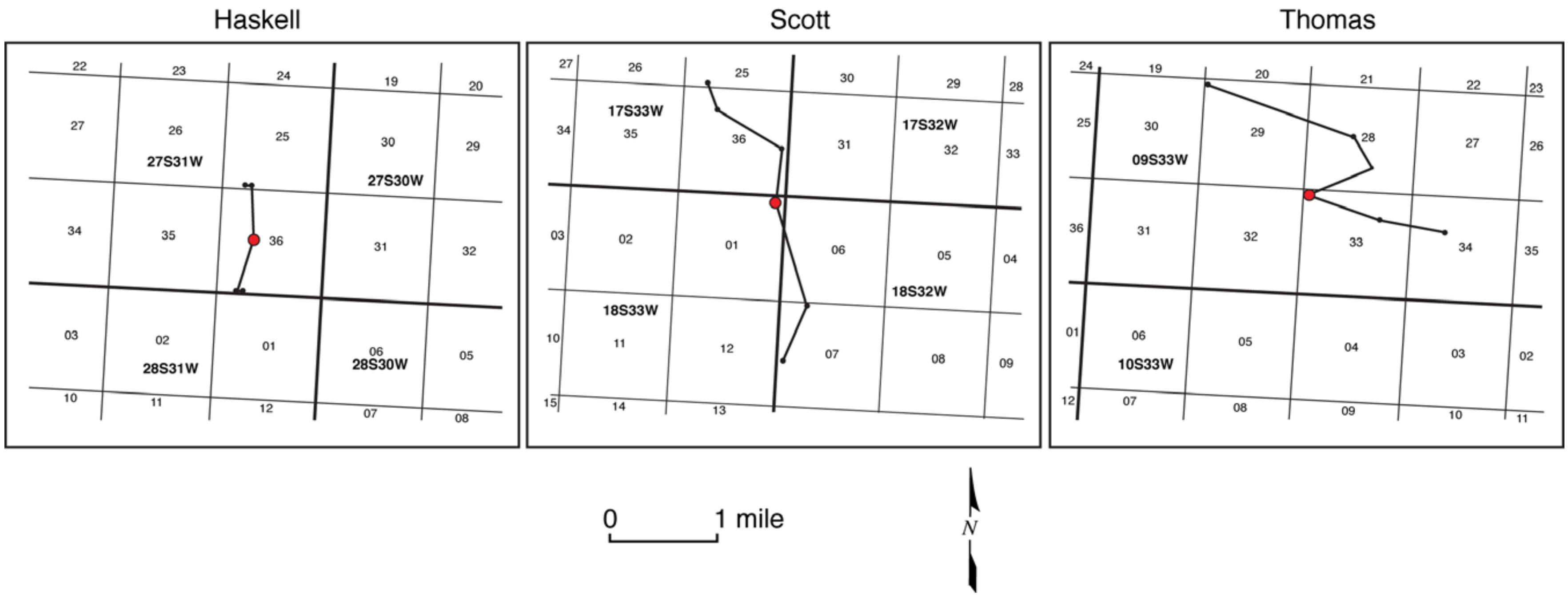


Figure 6. Locations of well logs used to construct the lithologic cross sections shown in Figure 5. The red dot indicates the index well location.

Haskell County Site (GMD3)

The Haskell County site is located in the SW/4 SE/4 NW/4 of Sec. 36, T.27S. R.31W (Figures 7 and 8). The location is in an area of local and district interest, characterized by high well and water-use density and large water-level declines, and concerns are high regarding these declines. This is also an area of intensive study by the DWR, which has installed pressure transducers in about 20 nearby wells and is monitoring meters on pumping wells. The site is at the center of a former impairment complaint, which was withdrawn before being resolved by the Chief Engineer. A major advantage of this site is the additional data available from the ongoing DWR investigation and the cooperative efforts of KGS and DWR.

The Haskell site is an area where there is a laterally extensive confining or semi-confining layer, with a relatively thin permeable layer consistently occurring just above bedrock. DWR has identified relatively shallow casings in the area that sample the water table above the confining layer, and deeper wells that are screened across both the shallow and deep zones. In addition to the general program objectives, this site will provide a test of how monitoring results and apparent depletion rates compare above, below, and across such a confining layer. This tests the applicability of regional indexing to a (semi-)confined water body.

The location is:

- In an area of water stresses and conflicts with high well and water-use density,
- In a hydrogeologically complex region (lithologic and bedrock topographic variability),
- Situated on a steep gradient in saturated thickness,
- Centered on an area where the main remaining water-bearing zone is deep, relatively thin, and semi-confined or confined.

Scott County Site (GMD1)

The location of the Scott County site is NE/4 NE/4 NE/4 of Sec. 1, T.18S. R.33W (Figure 9). The site is in the northern portion of the Scott-Finney bedrock depression. This is an area within the “region of interest” for municipal water supplies established as a GMD1 priority for ground-water management. There are no currently active monitoring wells in this part of the only major ground-water resource remaining in the area, so the study will provide an important addition to the annual network.

The ground-water body is the primary source of the municipal supply for Scott City, and there are active monitoring wells south of the city that will augment the study. The ground water in the depression is believed to be unconfined and hydraulically well-connected, which would facilitate indexing.

Haskell County Site with Surveyed Annual Water-Level (WIZARD) Wells and PDs

Figure 7. Haskell County site area with annual water-level (WIZARD) wells (yellow crosses) and points of diversion (black dots).

Haskell County Site with Surveyed DWR Wells (Yellow) and Points of Diversion (Black)

Figure 8. Haskell County site area showing wells that DWR is monitoring (yellow dots) and points of diversion (black dots).

Scott County Site with Annual Water-Level (WIZARD) Wells and PDs

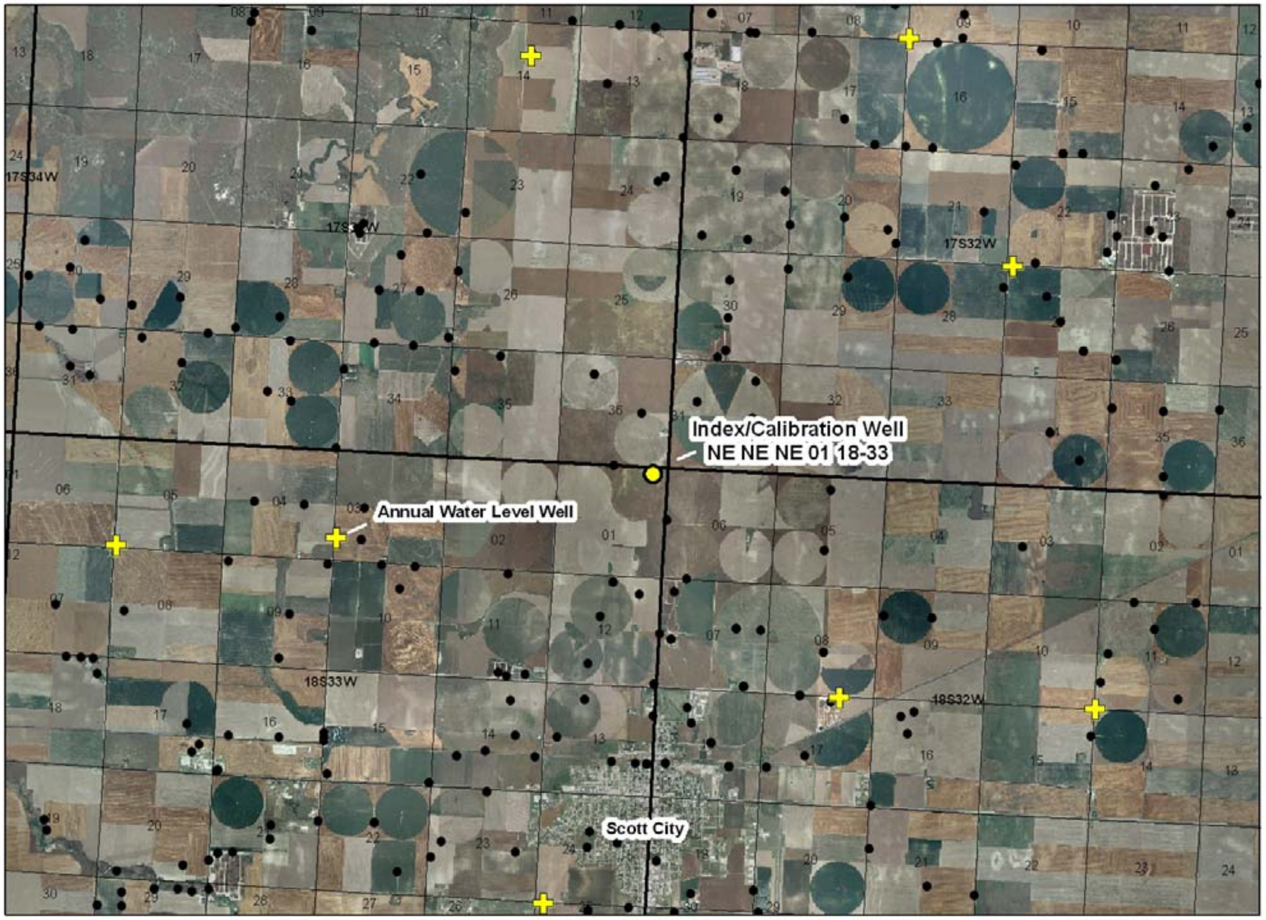


Figure 9. Scott County site area with annual water-level (WIZARD) wells (yellow crosses) and points of diversion (black dots).

The location is:

- Within a 5-mile radius of the Scott City municipal wells (consistent with GMD1 priorities on municipal supplies),

- In a major part of the local basin with adequate water supply remaining that is not monitored by existing program wells,

- A good test case for lateral extent of application of monitoring observations.

<u>Thomas County Site (GMD4)</u>

The Thomas County site location is NW/4 NW/4 NW/4 Sec. 33, T.09S. R.33W (Figure 10). The site is within a region that has been identified as a high priority in the GMD4 management plan and was an EQIP "quick response area" for grants to transition irrigated cropland to dryland farming. There has been some local initiative toward aquifer management in this area and the KGS previously developed and presented a water budget based on existing data. The site is close to Colby (where the GMD4 office is located, simplifying GMD support) and near the edge of the aquifer (a location particularly problematic for interpreting network results and modeling). The earlier study identified a number of weaknesses and uncertainties in the available data, as well as providing a review of conditions in the area. The index well study will benefit from that existing work.

The location provides improved coverage relative to the annual program wells in the area, and will provide a check on an annual water-level measurement well that consistently shows a lower water level than would be extrapolated from other monitoring wells in the vicinity. Saturated thickness is relatively consistent for several miles in all directions and nearby annual wells show strongly correlated water-level changes, making the area a good candidate for index wells.

The location is:

- Near the aquifer fringe, with a probable lateral recharge component from the upgradient thinly-saturated area, and possible stream channel contributions to recharge,

- In the area of an initial attempt at self-organization for considering possible subunit management by the irrigation community,

- In a location of low, but not desperately low, ground-water resources,

- Relatively close to an annual well that consistently gives results that seem out of character with the other measuring points in the region.

Thomas County Site with Annual Water-Level (WIZARD) Wells and PDs

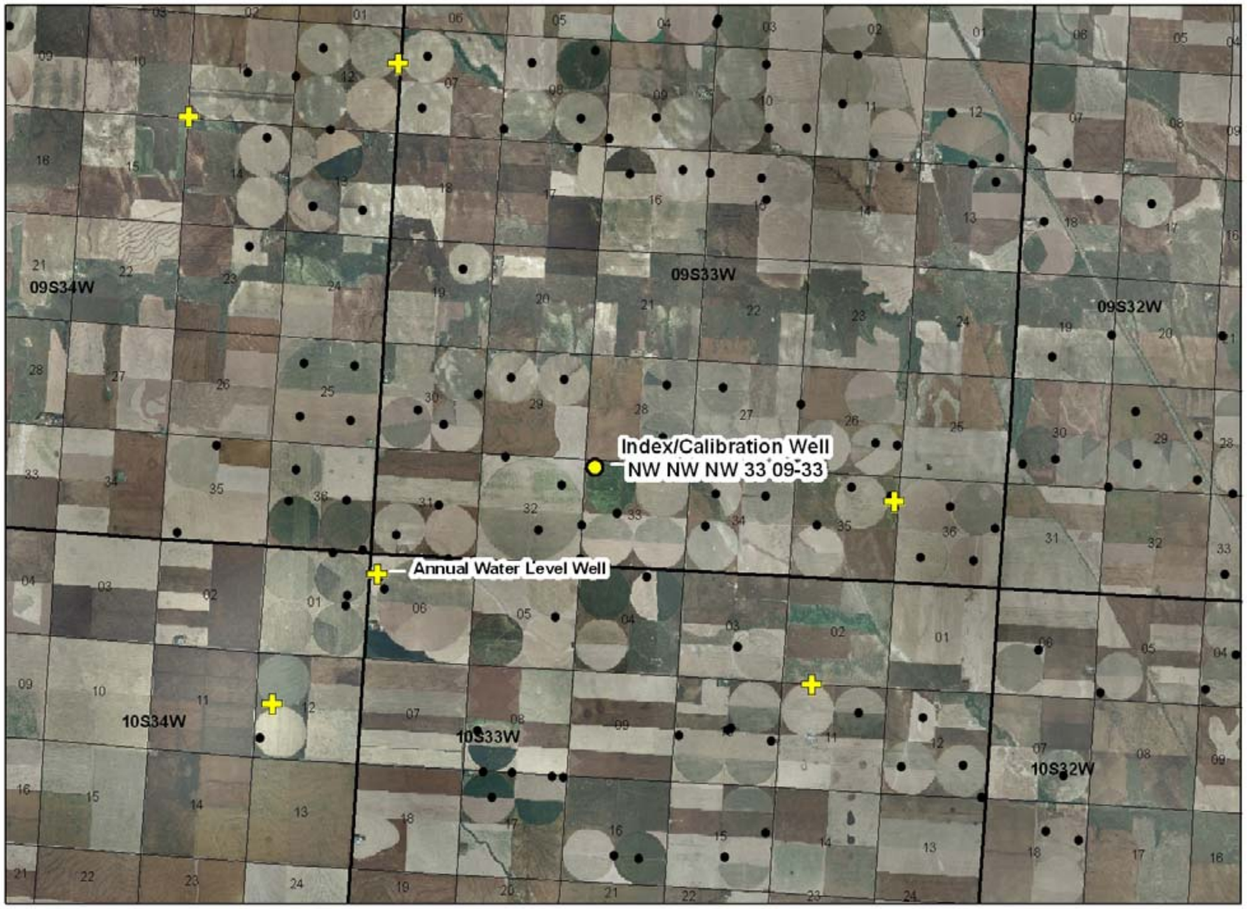


Figure 10. Thomas County site area with annual water-level (WIZARD) wells (yellow crosses) and points of diversion (black dots).

Well Construction and Data Transfer System

The index well casings are constructed of 2.5” PVC. Each well is screened in a 10-ft interval just above bedrock. Table 1 includes additional information on well construction. Water well completion records (WWC5 forms) containing well construction information and lithologic logs are in Appendix B, as are geophysical (natural gamma and resistivity) logs.

Initially, the Scott County well took longer to develop than expected and the static water level was lower than expected. It was determined that the well screen was probably plugged or partially plugged with grout and/or formation sediment. During discussions between the drilling contractor and the KGS, it was agreed that the contractor would return to the site to attempt to remove the blockage. On 20 August 2007, the contractor set up a top head drill rig with 1” pipe for drill string and a 2-1/4” bit. The crew ran drill string into the casing to 217 ft where the blockage was contacted, and drilled out blockage from 217 ft to total depth of 224.7 ft. The procedure was successful. The following day, the well developed normally and the water level rose to an expected elevation; continued monitoring of the water level indicates that it is responding to water-level changes in the aquifer.

Each site is equipped with a pressure transducer integrated with a data logger in the downhole sensor unit that collect data hourly. The sensors are vented to the surface and the transducers read the pressure or head of water above the sensors. The pressure readings are converted to feet of water above the sensors, and the readings are converted to water-level elevation during data processing.

Each site also is equipped with a telemetry system that transmits a pressure and a temperature reading to a database every 8 hours. These data are currently available in real time on a password-protected website, where the data may be viewed in tabular format, plotted, and downloaded. Figure 2 is a photograph of the Haskell site during telemetry installation, which is also typical of the other two sites.

Table 1. Index well information.

SITE_ID	Legal Location	Elevation (ft)	Screened Interval Depths (ft)
HASKELL	SW SE NW Sec. 36 T27S - R31W	2837.85	420-430
SCOTT	NE NE NE Sec. 01 T18S - R33W	2967.47	215-225
THOMAS	NW NW NW Sec. 33 T09S - R33W	3187.44	274-284

Results and Discussion

Lithology

As discussed in the installations section, Figure 5 illustrates the subsurface lithology along a cross section in the area of each of the three index well sites. Lithologic characteristics at the Haskell County index well were as expected based on review of surrounding well logs. From the surface down, the Haskell site is characterized by roughly 100 ft of fine-grained, relatively impermeable sediments below the surface, an intermediate thick layer composed of mainly sand and gravel, another thick (confining) clay layer, and a relatively thin, permeable sand and gravel zone just above bedrock. Most of the thick intermediate permeable zone at the Haskell site was saturated before development of the aquifer but now has been mostly dewatered. All the lithologic layers are laterally extensive and slope from the north to the south, as does the bedrock surface.

The Haskell County well is screened in the relatively thin permeable zone just above bedrock. This thin confined or semi-confined zone at the base of the aquifer is currently the main water-producing zone in the area. The DWR monitoring efforts are providing data from above and below the confining layer, and from some wells that are screened in both intervals.

The lithology at the Scott County site is more heterogeneous, and is characterized by mostly fine-grained sediments in the top half of the columns, with more permeable materials below. The remaining saturated sediments are relatively permeable and appear to be mainly unconfined.

The sediments are the most heterogeneous, in terms of lateral continuity at the three well locations, at the Thomas County site. Individual layers and lenses are relatively thin and interspersed. The remaining saturated thickness is composed of relatively permeable sediments, and, like the Scott County site, appears to be mainly unconfined.

Water Levels/Water Use

The slope of the water-level surface (hydraulic gradient) is mostly from west to east at each site. Early results illustrate a range of aquifer conditions, including confined or semi-confined conditions near the base of the aquifer at the Haskell County site.

Figure 7 is an aerial photo showing locations of the index well, points of diversion, and annual water-level measurement wells surrounding the Haskell County site. The annual wells are measured in January and are also referred to as WIZARD wells, in reference to the WIZARD Water Well Levels Database:
http://www.kgs.ku.edu/Magellan/WaterLevels/index.html.

As Figure 7 suggests, the Haskell site area is characterized by high well and water-use density. Figure 8 is similar to Figure 7, but zoomed in to identify the wells that DWR is monitoring (discussed in more detail below).

As indicated in Figure 4, the water table has declined more than 100 ft in the Haskell site area. The decline rate has been 4 to 5 ft/yr in the last decade. The water-level data, hydrograph, and other information for the WIZARD well 1.5 miles north of the Haskell County well may be viewed at the following link: http://hercules.kgs.ku.edu/geohydro/wizard/wizardwelldetail.cfm?usgs_id=374044100395001.

The hydrograph for the Haskell County index well (Figure 11) shows that the water level responds rapidly to nearby pumping wells turning on and off (the small, sharp changes in level), and has a large overall decline during the pumping season, which are indicative of confined or semi-confined aquifer conditions. Of the three index well sites, the range of water-table variations from August through mid-October was by far the greatest -- over 100 ft -- at the Haskell site. This variation is over two orders of magnitude greater than the fluctuations observed at the other two sites.

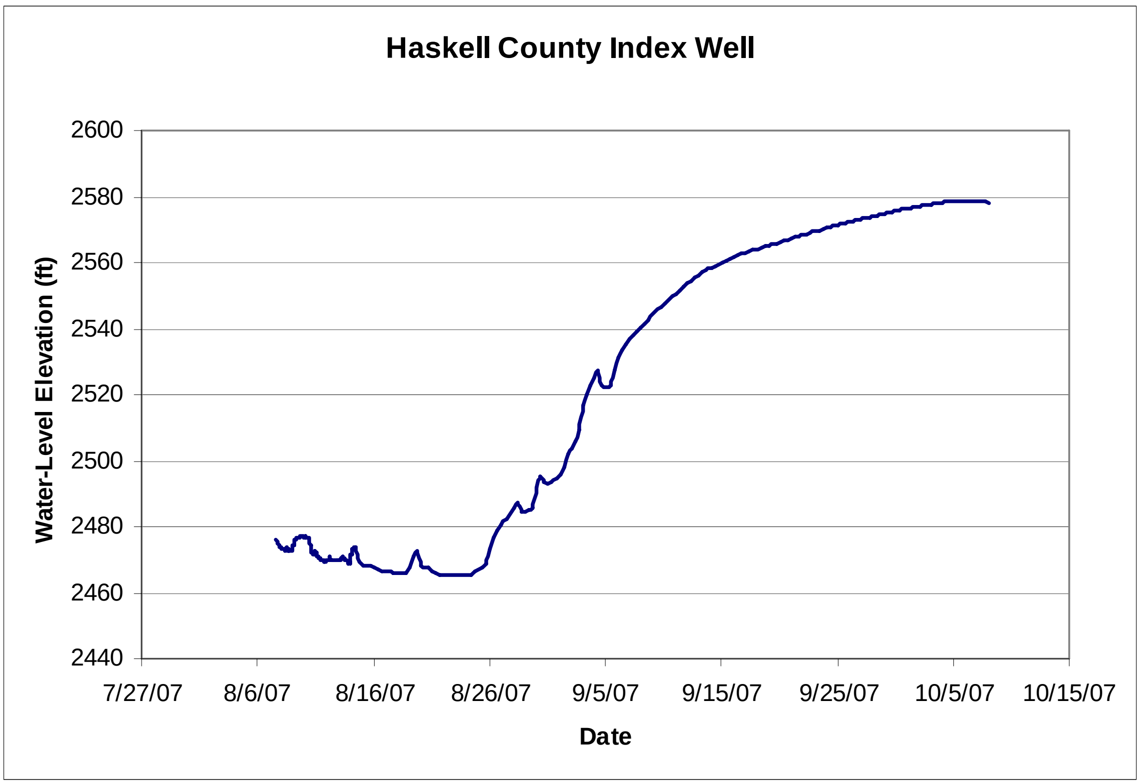


Figure 11. Hydrograph of Haskell County index well.

Rapid recovery of the Haskell water level began in late August, when area pumping was greatly reduced. However, as of mid-October, some pumping was still occurring in the area, so the full “no-pumping” recovery had not yet begun at that time.

The area around the Scott County well has experienced water-level declines of 50-100 ft since predevelopment (Figure 4). The decline rate appears to have slowed and has been less than 1 ft/yr over the past 10 years. The following WIZARD link is for the annual measurement well about three miles west of the Scott County index well: http://hercules.kgs.ku.edu/geohydro/wizard/wizardwelldetail.cfm?usgs_id=383053100573701 .

Since predevelopment, water-level declines in the 50-ft range have been observed in the vicinity of the Thomas County index well. Recent decline rates have been on the order of 1 ft/yr in the area. The link for the WIZARD well 3 miles east of the Thomas County index well is: http://hercules.kgs.ku.edu/geohydro/wizard/wizardwelldetail.cfm?usgs_id=391355100574901 .

Both the Scott and Thomas County index wells show active fine-scale responses, but only a few feet of net change over the August through mid-October period (Figures 12 and 13). The full vertical (elevation) scale on Figures 12 and 13 is only 3 ft, whereas the full vertical scale on Figure 11 (Haskell County) is 160 ft.

After the summer irrigation season ended, pumping continued near all the sites as winter wheat was planted so the full "no pumping" recovery had not yet begun by the end of the hydrographs in Figures 12 and 13. We will closely examine the hydrographs from all three sites and obtain additional measurements from annual wells during the recovery period to determine how representative the annual/January measurements are.

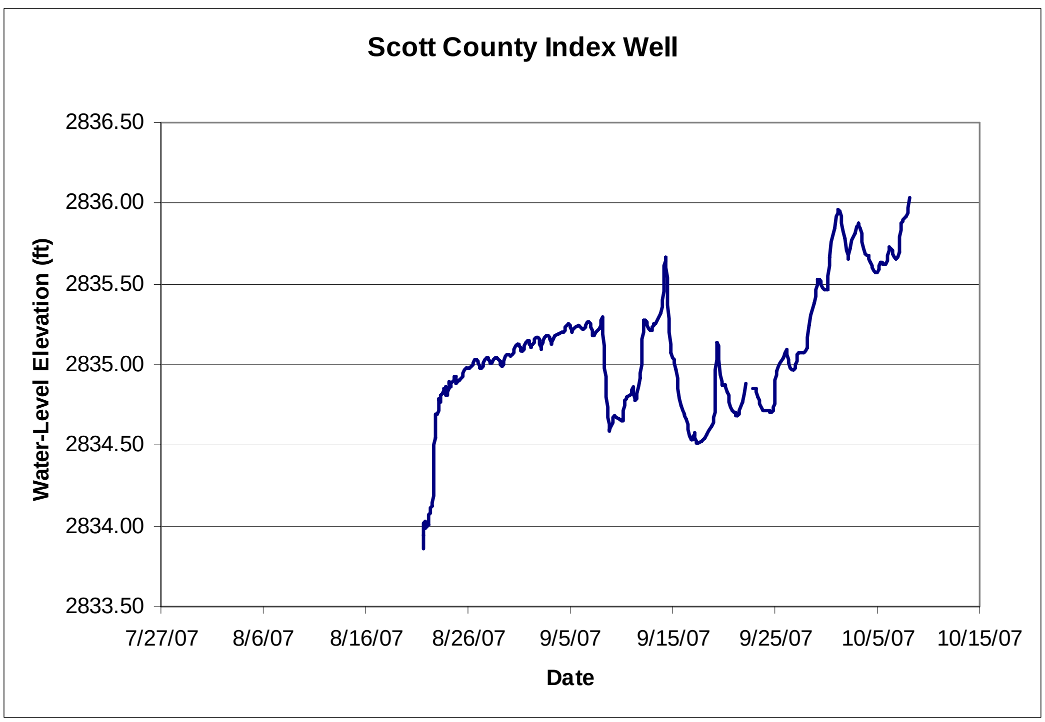


Figure 12. Hydrograph of Scott County index well.

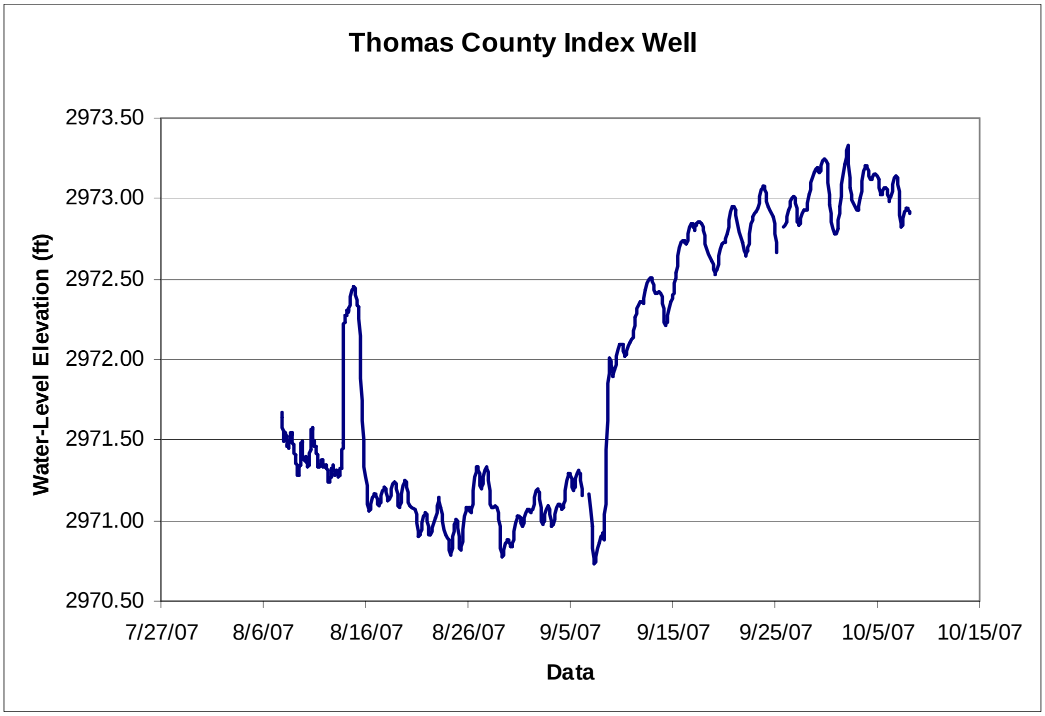


Figure 13. Hydrograph of Thomas County index well.

DWR Monitoring Efforts

The DWR has installed pressure transducers in approximately 20 wells in the vicinity of the Haskell County index well as part of monitoring activities regarding a former impairment complaint that has since been withdrawn. Locations of the wells are shown in Figure 8. DWR also is collecting metered water-use data from surrounding irrigation wells. Substantial efforts will go into the workup of these data, beginning with sorting out the respective elevations and depths.

It will be valuable to observe and important to understand what differences in water-level responses occur in different wells that are sampling different portions of the aquifer. For example, the Haskell County index well is screened in only the lower (semi-)confined portion of the aquifer. DWR is monitoring some wells that are only screened in the upper permeable portion of the aquifer and some wells that are screened over multiple intervals, which is common in many of the annual network wells and most irrigation wells.

Analysis of preliminary data indicates that the water levels in the shallow wells show relatively little response, whereas water levels in some deeper and/or pumping wells show relatively large responses. In fact, the hydrograph from a deep pumping well one-half mile north of the Haskell index well is very similar to the hydrograph from the index well in both shape and magnitude of water-level change. It is not known how laterally extensive the confined zone is, but it appears to be the primary source of water remaining for irrigation well production, particularly to the north.

<u>Elevation Surveys (Provisional)</u>

Elevations at six WIZARD wells surrounding each of the index wells were surveyed by a licensed land surveyor (Table 2). These data should be considered provisional. Datums will have to be verified using site photos, and possibly field inspections for some of the sites. These provisional elevation data are compared with the elevations in the WIZARD database in Table 2. The apparent difference between the surveyed elevations and WIZARD elevations is less than 2 ft at most of the 18 sites. However, the difference is greater than 5 ft at one site. If changes are made in a local network of measuring points, uncertainties of just a foot or two can obscure annual decline trends, which are less than a foot per year in Scott and Thomas counties.

Future Work

Year 2 of the program will be data intensive. In coordination and cooperation with the DWR, we will conduct a full work-up and calibration of the numerous data being collected around the Haskell County site. These data include the newly-surveyed elevation data, well depths and screened interval information, water-level changes and pumping meter data.

The index wells are being added into the annual measurement program, and the elevation survey data for the annual wells will be verified and entered into the WIZARD database. Thus, the annual measurement program will be improved with better elevation accuracy and higher (high-quality) data density.

It is clear from previous studies that recovery continues after the January water-level measurements in some wells. We will watch the recovery period very carefully to gain a better understanding of when full recovery occurs in the different wells/regions and how representative and spatially consistent the annual/January measurements are. With the assistance of the DWR and the GMDs, we will collect additional measurements from annual wells surrounding the index wells, particularly during the recovery period.

We will continue to collect and analyze data from the index wells, coordinating with the DWR monitoring program for the wells surrounding the Haskell site. We will compare pumping records with well hydrographs and assess interactions between pumping patterns and water-level changes. In addition to the general program objectives, the Haskell site will provide a test of how monitoring results and apparent depletion rates compare above, below, and across a (semi-)confining layer. This tests the applicability of regional indexing to a (semi-)confined water body. As a part of the Haskell site investigations, we will examine the lithologic logs of neighboring wells and other wells in an outward direction from the index well location to map the lateral extent of the (semi-)confined zone.

Table 2. Comparison of surveyed elevations (provisional) and elevations in the WIZARD database for annual wells.

HASKELL COUNTY VICINITY

SITE_ID	LOCATION	USGS_ID	ELEV_SURVEYED	ELEV_WIZARD	DIFFERENCE (FT)
HS21	SW SE SW 24 27-31	374044100395001	2821.67	2816	5.67
HS22	SW SW NW 31 27-31	373929100453601	2893.22	2895	-1.78
HS23	NE NW NW 08 27-30	374319100375801	2789.93	2791	-1.07
HS24	NW NW NW 08 27-30	374317100375501	2792.27	2790	2.27
HS25	SW NW NW 23 27-30	374125100344101	2771.18	2773	-1.82
HS26	NE NW NW 17 28-30	373709100374701	2818.32	2817	1.32

SCOTT COUNTY VICINITY

SITE_ID	LOCATION	USGS_ID	ELEV_SURVEYED	ELEV_WIZARD	DIFFERENCE
SC2	NW SW SW 03 18-33	383053100573701	3009.10	3008	1.10
SC3	NW NW NW 25 18-33	382803100552301	2974.82	2972	2.82
SC4	NW SW NE 14 17-33	383448100555801	3016.81	3014	2.81
SC5	NW NW NW 16 17-32	383501100520601	2980.82	2980	0.82
SC6	NW NW NW 27 17-32	383316100505801	2989.24	2990	-0.76
SC7	NE NW NE 17 18-32	382947100522902	2974.56	2973	1.56

THOMAS COUNTY VICINITY

SITE_ID	LOCATION	USGS_ID	ELEV_SURVEYED	ELEV_WIZARD	DIFFERENCE
TH2	SE NE NE 35 09-33	391355100574901	3145.31	3145	0.31
TH3	SW NW NW 06 10-33	391303101031701	3191.91	3191	0.91
TH4	NW NE NW 11 10-33	391217100583201	3139.87	3140	-0.13
TH5	SE SW NW 12 10-34	391200101041601	3220.55	3220	0.55
TH6	SW SW SW 11 09-34	391646101052901	3179.13	3180	-0.87
TH7	NE SE NE 12 09-34	391718101032301	3202.16	3199	3.16

We will continue to compare and contrast the characteristics of the locales (in terms of potential subunits). For example, the potential approach for an aquifer subunit in the Scott City area is a set of five-mile circles around each of the municipal water rights, which appear as the single circle-shaped red line in Figure 14. The Scott County index well is located approximately in the center of the northern half of the large red circle. We will assess how representative the index wells are of the water-level changes within potential subunits such as this circled-shaped area in Figure 14, as well as how the index wells can be used to calibrate WIZARD wells and other water-level measurements within subunits.

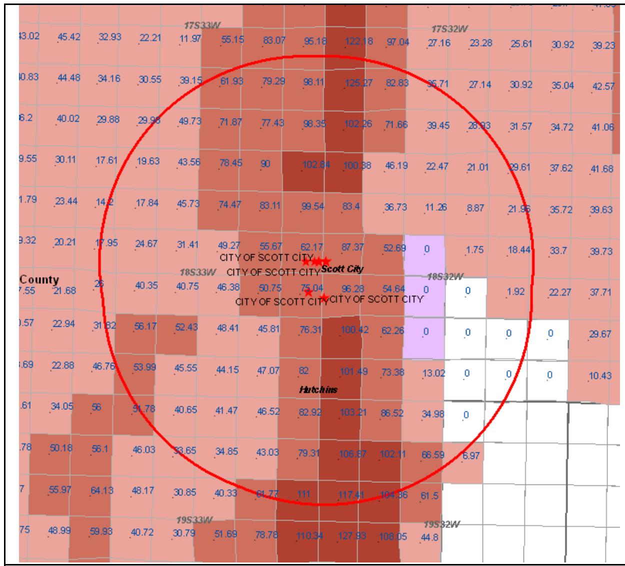
In addition, we will examine the regional/broader aquifer conditions of subunit areas and what further information is needed to assess the utility of the index well approach. We will maintain close liaison with the GMDs to develop the program and interpretation of results in ways that will address management implications.

Finally, we will make the data promptly and easily available to the KWO, DWR, GMDs, and the landowners who have allowed the use of their property for well installation.

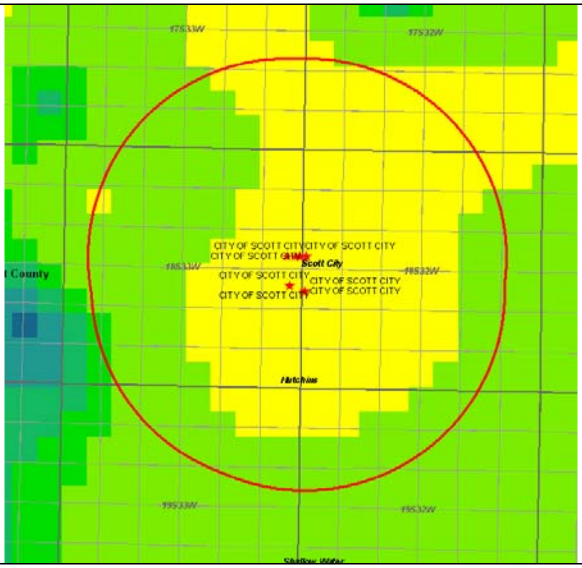
Acknowledgments

We are grateful for the support, assistance, and cooperation of the staffs of the Kansas Water Office, the Division of Water Resources of the Kansas Department of Agriculture, the managers and staffs of Groundwater Management Districts 1, 3 and 4, and especially for the cooperation of Jarvis Garetson (the Garetson Brothers), KBUF Inc., and Steve and Marilyn Friesen in making their properties available for installation of the wells.

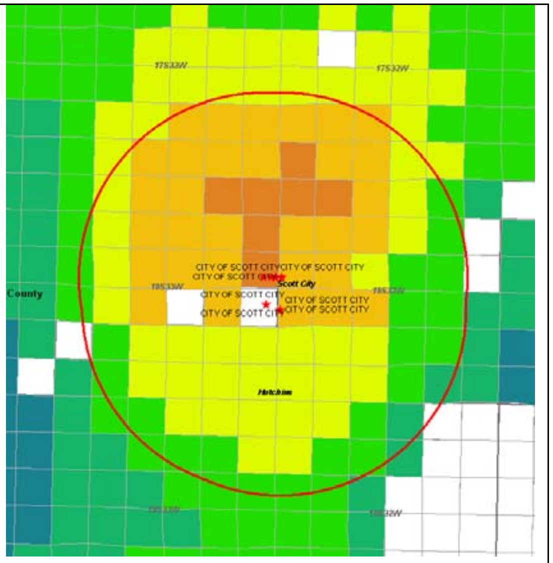
This report was reviewed by other members of the KGS Geohydrology Section. Susan Stover of the Kansas Water Office provided instructive comments on an earlier draft of this report. Mark Schoneweis assisted with graphics and ShyAnne Mailen assisted with the final production of this report.



Scott City water supply – saturated thickness (Avg 04-06), in ft. Blue numbers are estimated saturated thickness values at the section center.



Scott City water supply – change in saturated thickness 96-06, in ft.



Scott City water supply – average density of use (5-mile smoothing radius), in acre-ft per square mile (AF/sq mi).

Figure 14. A possible subunit approach in GMD1 based on a five-mile radius around the municipal water rights of Scott City.

Appendix A.

Calibration Monitoring (a.k.a. “Index”) Well Program Rationale

(updated and modified from a KGS draft document of 16 November 2006)

Background and Issues:

Effective management of priority aquifer subunits (i.e., areas in which prompt, active intervention may be required to maintain or extend access to ground-water resources) must be supported by hydrologic data that:

- Are technically and scientifically defensible;
- Can be accepted both by government agencies and members of the affected community;
- Have the accuracy and precision to adequately detect and quantify changes (e.g., in water in storage or saturated thickness) on time scales of a few years and spatial scales of townships or smaller, and to relate these changes to changes in water use or specific management-related actions.

Data must be usable to enforce or implement measures (incentives or restrictions) that will have profound economic effects on individuals and the community. It is essential that the basis for these measures be acceptable to stakeholders, and that the effects of management measures be subject to quantitative evaluation. The adequacy of any specific dataset or approach is ultimately determined by the governing body (e.g., GMD Board of Directors, or Chief Engineer) in the context of specific local conditions and management objectives, and cannot be rigorously specified in terms of universal, exclusively technical, criteria. However, general guidelines can be provided for developing and evaluating the monitoring program used to support enhanced management of localized areas.

The existing annual monitoring program and the data it provides have been effectively used to identify areas deserving priority for enhanced management – regions with high rates of water-level decline and/or remaining ground-water resources so limited that usage of appropriated quantities is no longer possible. However, this information lacks the accuracy and precision needed to permit reliable interpretation of annual or near-annual changes. The problems have been reviewed extensively in KGS OFR 2002-25 (http://www.kgs.ku.edu/HighPlains/OHP/index.htm; see especially parts D and F). To summarize briefly:

1. Annual program wells are measured at the same time in early January. This is often far in advance of full water-table recovery from the pumping stresses of the previous season, and the deviation from recovery differs from well to well and from year to year. This variability in recovery introduces substantial year-to-year uncertainty.
2. Program wells are distributed geometrically (very approximately one/township), based on assumed values of acceptable uncertainty for regional, multi-year estimates of water-table elevation, and to provide a network that is a reasonable statistical sample of water levels with a number of wells that is within cost considerations of the joint DWR-KGS program.
3. The aquifer is treated as a uniform, varying hydrologic surface, which does not account for the spatially abrupt changes observed in the cross-validation of the annual monitoring results.

4. Elevation control is based on topographic maps rather than surveys, so a change in the well measured can cause a water-table elevation change uncertainty of up to several feet.
5. Historic well selection did not consider proximity to other pumping wells, including those that may be in use at the time of measurement.
6. Most of the wells measured are irrigation wells, which means that they are constructed to maximize yield rather than quality of measurement, and which exacerbates the problem identified in point 1.
7. The statistical analysis used is based on assumptions about the magnitude and distribution of uncertainty that are considered reasonable, but which have not been calibrated against field observations or well tested theory.

There are no systematic, universally accepted approaches to overcoming the deficiencies of the annual monitoring program in order provide the quantity and quality of data desired for subunit management – that is, to move from a system that can evaluate large-scale change over time periods of 5-10 years to one that can characterize smaller areas on near-annual time scales. Since the needs for accuracy, precision, and spatial and temporal density of measurements will depend on both local hydrogeology and the specific management objectives, detailed data and monitoring needs for priority areas are best considered on a case-by-case basis. However, many issues can be resolved at a general level, which greatly simplifies case-by-case decisions. This project, which will combine high-quality continuous water-level monitoring in individual wells with additional well measurements in the same general vicinity at greater frequencies and spatial densities than used in the annual management program, will provide quantitative case studies that can be used as quantitative examples of possible monitoring strategies.

Simply measuring more wells more often in a priority area is a straightforward option requiring little investment, but it is an inefficient, labor-intensive approach that still does not address some of the problems listed above (3, 4, and 6, and possibly all or part of 2, 5, and 7). An expanded hand measurement program is a logical way to establish better local baseline data and experimentally assess the utility of that approach, but longer-term monitoring should be designed for ease and consistency of application. Modeling is attractive at larger scales, but at the local level the quality of output is controlled by the quality of the input data. The calibration well project, however, takes a general step forward in addressing a number of relevant issues. Specifically, from the list above, items 1, 3, 4, 5 and 6 are not issues in the present study, and item 7 will be addressed in the analysis. At least for the areas in question, the results will therefore provide information on the accuracy and precision of data needed and available at local scales, and on the issues involved in expanding these scales to cover larger areas. Between them, the study sites should represent enough hydrogeologic variety to provide some sense of the range of monitoring approaches needed.

Program description:

The monitoring calibration (index) well program is a pilot study of an improved approach to measuring hydrologic responses at the local level. The hypotheses to be tested are that

1. Properly designed, sited, and measured wells can yield measurements that, supported by supplemental measurement of other wells in the vicinity, are sufficiently accurate and representative of local water-table behavior to use in intensive management programs; and
2. Consistent deviations from the behavior of a calibration well indicate aquifer heterogeneity; such results can be interpreted to refine subunit definitions and characteristics or to inform the interpretation of water table responses over larger/other areas.

There are two primary aspects to the program: well and measurement design, and siting. By using carefully installed monitoring wells of proven design, combined with continuous pressure transducer measurements of water level, points 1 and 6 above are addressed, and the results can serve to either test or augment the analyses (point 7). Since a limited number of wells are being tested, vertical surveys to establish network "hydrobenchmarks" are feasible (point 4).

Points 2-5 are addressed by the well siting (discussed in more detail below). It is important to note, however, that the siting and local purpose of the well are also key factors in generating local interest in and acceptance of the measurement approach, and thereby of the feasibility of management subunits. To this end, site selection that addresses local needs, interests, and perceptions becomes an important factor along with the hydrogeologic considerations. This is particularly true because of the practical need to rely on GMD assistance for local supplemental measurements, information, and maintenance support and possibly for financial supplementation.

Siting criteria:

The technology of installation and measurement is generally well understood and feasible, so the major issues are related to well location. The general technical criteria considered are that the location chosen addresses one or more of the concerns noted above. Two major issues can be identified: homogeneous vs. heterogeneous aquifer regions, and confined vs. unconfined aquifers. In order to obtain the most useful results (and potentially to provide an installation of continuing utility), selection needs to focus on:

1. Regions where there is good reason to believe that the aquifer is locally relatively homogeneous, whether confined or unconfined.
2. In the case of a confined system, it should be possible to obtain data from above and below the confining layer (note that annual program wells are often screened or gravel-packed across multiple layers).
3. In all cases, it is essential to have enough remaining saturated thickness to ensure hydraulic connection over a reasonable area, and if possible, enough so that the

aquifer lifetime in the region is long enough to use the installation in development and implementation of an actual management program.

4. In addition to the technical considerations, it is desirable to have the installations in a region that could qualify as a priority subunit, and especially to work in locations where local and/or district interest and concern are high.
5. Also a consideration, in addition to tests of the hypotheses and possible practical application of the results, is augmentation or correction of the annual program network, as a first step toward comparison and intercalibration.
6. Distance from and relationship to both pumping wells and network wells.

Review of site selections:

Initial screening for all three GMDs consisted of two concurrent processes --
reviewing the estimated lifetime and saturated thickness maps (criteria 3 and 4), and other data where available (e.g. the PST data in GMD3 – criterion 1), and,
discussing with the GMD managers options and priorities relevant to hydrologic and political situations within each GMD (criterion 4). Based on these efforts, we focused on one or a few general areas in each GMD, and considered criteria 1, 2, 5, and 6, as well as questions of access, landowner permission, etc. In each case, it was possible to identify possible sites.

GMD4: The south Thomas county region where there has been some local initiative toward aquifer management and where KGS developed and presented a water budget based on existing data in 2006, was selected as the area of interest. In addition to fitting the selection criteria, it is close to Colby (simplifying GMD support) and on the edge of the aquifer (a location particularly problematic for interpreting network results and modeling). The selected site is 9S 33W N1/2 of sec 33 (NW corner). Considerations – location south of the South Fork Solomon River provides improved coverage relative to the annual program wells in the area, and will provide a check on well 10S 33W 06BBC, which consistently shows a lower water level than would be extrapolated from other monitoring wells in the vicinity. Saturated thickness is relatively consistent for several miles in all directions and the well hydrographs for 9S 33W 35AAD and 9S 34W 12ADA show strongly correlated water-level changes, making the area a good candidate for index wells. Landowner permission has been obtained.

GMD3: The vicinity of the Garetson impairment action was selected as an initial target (Criteria 3 and 4, plus the major advantage of the additional data available from the ongoing DWR investigation). Following discussions and an intensive review of well logs for the area, a location in the SE1/4 of the NW 1/4 Section 36, 27S 31W has been identified (depending on access it may be moved slightly).
Considerations – this is an area where there is a laterally extensive confining or semi-confining layer, with a deep sandy layer consistently occurring just above bedrock. Further, DWR has identified shallow casings in the area that sample the water table above the confining layer (criteria 1 and 2). In addition to the general program objectives, this site will provide a test of how monitoring results and apparent depletion rates compare above, below, and across such a layer. This tests the applicability of

regional indexing to a (semi)confined water body. In addition to providing enhanced local monitoring, DWR has identified landowners willing to cooperate with test well installation.

GMD1: The GMD has adopted protection of municipal water supplies as a priority; all of the areas surrounding municipalities (and their water rights) were reviewed with the Manager for suitability. Scott City and Sharon Springs were identified as best meeting the initial criteria, and Scott City was identified as a preferred target. There was agreement that the priority area is the Scott-Finney depression north of Scott City. There are no currently active monitoring wells in this part of the only major remaining ground water resource in the area, so the study would provide an important addition to the annual network (criteria 3, 5). The water body is the primary source of the municipal supply (criterion 4), and there are active monitoring wells south of the city that will augment the study. The ground water in the depression is believed to be unconfined and hydraulically well-connected (criterion 1), which would facilitate indexing. On an initial review, the preferred location would be along the south or west border of sec 31, 17S 32 W. The west boundary is the highway right-of-way, which means that drilling might not require landowner cooperation, and elevation surveys would be easier.

Taken together, the selected sites make the maximum use of additional data sources, local interest, and relevance to other goals and programs. They address a variety of ground-water settings that are both individually and generally important, and will contribute generalizable knowledge as well as specific local benefit.

Implementation:

The wells will be installed under contract to KGS specifications for monitoring wells. Following installation and development, the wells will be equipped with recording pressure transducers, and water levels will be measured with a tape initially and at intervals throughout the project to calibrate the transducer readings. Also, we are looking into deploying telemetry capability for remotely accessing data and monitoring for possible problems and/or malfunctions.

We anticipate that the loggers will be set to acquire data every hour (with data transmission via telemetry every 8 hours), which should be adequate to observe responses to nearby pumping and barometric changes (if any); however, frequency of measurement can be adjusted over a very wide range.

It will be very desirable to obtain surveyed elevation data for the wells early in the program period; similar surveys of the nearby wells (especially annual program wells) would further enhance the results.

Analysis and dissemination of data

Transducer records will be data-based and linked to the WIZARD well listing to be viewable and retrievable. Hand measurements will be uploaded to WIZARD via the remote entry capability. Additional websites presenting comparisons and analysis results can be made available; but this needs concurrence of the GMDs and other agencies as to access and conclusions presented.

Well records will be analyzed by standard curve-fitting and extrapolation techniques to project the time and elevation of complete recovery. The consistency of the other measured wells with the calibration well will be assessed both visually and statistically to determine the level of confidence with which the calibration well results can be applied to water-table behavior in adjacent areas. The measured "subunit" behavior will be compared to inferences based on the annual measurement program (both with and without the calibration well included in the network) to estimate present network reliability and the degree of improvement resulting from inclusion of the calibration well.

In addition to making the data generally available and distributing appropriately the resource- and management-oriented conclusions, we anticipate that the results will be publishable as scientific articles or technical reports, which can serve as an information resource in addressing similar issues elsewhere.

Duration and requirements of program

It is anticipated that two full years after completed well installation will be required to carry out formal subunit-level comparisons and analyses, although substantial amounts of useful information and preliminary analyses will occur within the first year and expand progressively.

An estimated 5-year period is the probable duration of the main phase of the program. That period will extend into the time by which aquifer subunits are expected to be designated and operating as management entities, and will provide adequate time for analysis of the monitoring well implications for the annual program network as well as for the characterization and management of the immediate (subunit-scale) vicinity.

It is expected that these wells will become an important part of the annual program network in addition to any possible role in local subunit management; thus their existence and use could extend into the indefinite future. This raises the question of the source of support for long-term maintenance and measurement.

Since this relates closely to overall KGS support for and involvement in Ogallala efforts, the exact sources and amounts of resources required (personnel, funding) cannot realistically be spelled out, other than to say that (a) some additional resources will be needed, and (b) they will be less than the present total devoted to Ogallala support.

Expected outcomes and criteria for success

Success can be measured by:

1. Acquisition of the desired data (continuous calibration well records and supporting measurements from other wells in the vicinity);
2. Completion of the specified analyses and interpretations; and,
3. Application of the results to improved management and/or monitoring programs.

The first two of those can be promised with confidence by the KGS Geohydrology section; the third depends on responses and reactions by others. In the outcomes description below, **bold type** indicates the products or results the completion of which will be a criterion for success of the overall effort.

We will obtain detailed data on maximum drawdown and water-table recovery characteristics, and relate these to observations made in pumping wells and annual program wells in the vicinity. From this **we will evaluate the year-to-year accuracy and precision of point estimates made from annual program results, and produce specific recommendations for modifying the program and/or interpreting the results to make improvements in the utility of the annual program data**.

The correlation between the calibration well and nearby wells will determine the extent (in both time and space) to which the calibration well can be used as an index or proxy for local water-table behavior. In areas where the extent is large we will have achieved a major improvement in ongoing data for management purposes; **if there are locations near boundaries where the relationship breaks down, we will be able to identify the reasons** (e.g, lithology, topography, etc.). The extent of applicability will provide important inputs for the design and monitoring of subunit areas.

We expect that the wells will be included in the annual measurement program, as well as adopted by the GMDs for management support, although these decisions will be made by others**. Incorporation of continuously monitored, non-pumping wells plus a high density of local measurements into the network will precipitate a reassessment of the methods of determining confidence level at the local scale.** Whether improved confidence at the local level (a certain result) leads immediately to improved confidence in the overall network results will depend on the findings, but **the results of this calibration well program will certainly make it <u>possible</u> to improve overall network confidence on a scale of years.**

Appendix B.

Water Well Completion Forms and Geophysical Log Plots for the Index Wells

157 8726 Site 3 OBGMD-3

Corrected Copy
Form WWC-5

WATER WELL RECORD

Division of Water Resources, App. No.

1 LOCATION OF WATER WELL: County: Haskell

Fraction: SW 1/4 SE 1/4 NW 1/4 | Section Number: 36 | Township Number: T 27 S | Range Number: R 31 E (W)

Distance and direction from nearest town or city street address of well if located within city? Approximately 11 1/2 miles west and 4 miles north of Montezuma

Global Positioning Systems (decimal degrees, min. of 4 digits)
Latitude: 37.657017
Longitude: -100.664848
Elevation: Unknown
Datum: NAD83
Data Collection Method: WAAS GPS Unit

2 WATER WELL OWNER: ~~University of Kansas Center for Research, Inc. 2385 Irving Hill Road Lawrence, KS 66045-7563~~ Kansas Geological Survey 1930 Constant Ave. Lawrence, KS 66045
RR#, St. Address, Box #
City, State, ZIP Code

3 LOCATE WELL'S LOCATION WITH AN "X" IN SECTION BOX: N; NW (x), NE, SW, SE; W, E; S

4 DEPTH OF COMPLETED WELL 432 ft.

Depth(s) Groundwater Encountered (1) ft. (2) ft. (3) ft.

WELL'S STATIC WATER LEVEL 317.65 ft. below land surface measured on mo/day/yr 06-20-07

Pump test data: Well water was Not checked ft. after hours pumping gpm

Est. Yield Unknown gpm: Well water was ft. after hours pumping gpm

WELL WATER TO BE USED AS: 5 Public water supply 8 Air conditioning 11 Injection well 1 Domestic 3 Feedlot 6 Oil field water supply 9 Dewatering (12) Other (Specify below) 2 Irrigation 4 Industrial 7 Domestic (lawn & garden) 10 Monitoring well — Observation

Was a chemical/bacteriological sample submitted to Department? Yes ___ No ✓ If yes, mo/day/yrs Sample was submitted

Water well disinfected? Yes ___ No ✓

5 TYPE OF CASING USED: 1 Steel (2) PVC 3 RMP (SR) 4 ABS 5 Wrought Iron 6 Asbestos-Cement 7 Fiberglass 8 Concrete tile 9 Other (specify below)

CASING JOINTS: Glued ✓ Clamped Welded Threaded

Blank casing diameter 2 1/2 in. to 420 ft., Diameter in. to ft., Diameter in. to ft.

Casing height above land surface 24 in., weight 1.45 lbs./ft. Wall thickness or gauge No. .276

TYPE OF SCREEN OR PERFORATION MATERIAL: 1 Steel 3 Stainless Steel 5 Fiberglass (7) PVC 9 ABS 11 Other (Specify) 2 Brass 4 Galvanized Steel 6 Concrete tile 8 RM (SR) 10 Asbestos-Cement 12 None used (open hole)

SCREEN OR PERFORATION OPENINGS ARE: 1 Continuous slot (3) Mill slot 5 Gauzed wrapped 7 Torch cut 9 Drilled holes 11 None (open hole) 2 Louvered shutter 4 Key punched 6 Wire wrapped 8 Saw Cut 10 Other (Specify)

SCREEN-PERFORATED INTERVALS: From 420 ft. to 430 ft., From ft. to ft.
From ft. to ft., From ft. to ft.

GRAVEL PACK INTERVALS: From 325 ft. to 435 ft., From ft. to ft.
From 435 ft. to 460 ft., From ft. to ft.

6 GROUT MATERIAL: (1) Neat Cement 2 Cement grout 3 Bentonite (4) Other Bentonite Holeplug

Grout Intervals: From 4 ft. to 325 ft., From ft. to ft., From 0 ft. to 4 ft.

What is the nearest source of possible contamination: 1 Septic tank 2 Sewer lines 3 Watertight sewer lines 4 Lateral lines 5 Cess pool 6 Seepage pit 7 Pit privy 8 Sewage lagoon 9 Feedyard 10 Livestock pens 11 Fuel storage 12 Fertilizer Storage 13 Insecticide Storage 14 Abandoned water well 15 Oil well/gas well (16) Other (specify below) None known

Direction from well? How many feet?

FROM	TO	LITHOLOGIC LOG	FROM	TO	PLUGGING INTERVALS
0	2	Topsoil	95	107	Sand, fine to coarse
2	28	Clay, tan, silty, some caliche	107	115	Clay, tan, white, sandy, with some caliche
28	34	Sand, fine to coarse	115	130	Sand, gravel, fine to medium
34	45	Clay, tan, white, silty	130	145	Sand, gravel, fine to coarse, with clay
45	56	Clay, red, brown, with caliche			streaks, thin, yellow
56	63	Sand, fine to very fine	145	245	Sand, gravel, fine to coarse
63	68	Clay, tan, white, with streaks of caliche and	245	250	Sand, gravel, fine to coarse, with clay, gray
		cemented sand, thin	250	280	Sand, gravel, fine to coarse, with clay
68	80	Sand, fine to very fine, silty			streaks, thin, yellow
80	95	Cemented sand, soft, with clay, brown, and	280	296	Sand, gravel, fine to medium, with clay
		caliche streaks			streaks, thin, yellow

CONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was (1) constructed (2) reconstructed (3) plugged under my jurisdiction and was completed on (mo/day/year) 06-20-07 and this record is true to the best of my knowledge and belief. Kansas Water Well Contractor's License No. 185 This Water Well Record was completed on (mo/day/year) 06-26-07 Under the business name of Clarke Well & Equipment, Inc. by (signature) [signature]

INSTRUCTIONS: Use typewriter or ball point pen. *PLEASE PRESS FIRMLY* and *PRINT* clearly. Please fill in blanks, underline or circle the correct answers. Send top three copies to Kansas Department of Health and Environment, Bureau of Water, Geology Section, 1000 SW Jackson St., Suite 420, Topeka, Kansas 66612-1367. Telephone 785-296-5522. Send one to WATER WELL OWNER and retain one for your records. Fee of $5.00 for each constructed well.

158 8726 Site 3 OBGMD-3 (Cont'd) **Corrected Copy**

WATER WELL RECORD Form WWC-5 Division of Water Resources; App. No.

1 LOCATION OF WATER WELL: County: Haskell	Fraction SW 1/4 SE 1/4 NW 1/4	Section Number 36	Township Number T 27 S	Range Number R 31 E (W)

Distance and direction from nearest town or city street address of well if located within city? Approximately 11 1/2 miles west and 4 miles north of Montezuma

Global Positioning Systems (decimal degrees, min. of 4 digits)
Latitude: 37.657017
Longitude: -100.664848
Elevation: Unknown
Datum: NAD83
Data Collection Method: WAAS GPS Unit

2 WATER WELL OWNER: ~~University of Kansas Center for Research, Inc. 2385 Irving Hill Road Lawrence, KS 66045-7563~~ Kansas Geological Survey 1930 Constant Ave. Lawrence, KS 66045
RR#, St. Address, Box #
City, State, ZIP Code

3 LOCATE WELL'S LOCATION WITH AN "X" IN SECTION BOX: N, W, E, S; NW, NE, SW, SE (X in NW quarter)

4 DEPTH OF COMPLETED WELL ...... ft.
Depth(s) Groundwater Encountered (1) ...... ft. (2) ...... ft. (3) ...... ft.
WELL'S STATIC WATER LEVEL ...... ft. below land surface measured on mo/day/yr ......
Pump test data: Well water was ...... ft. after ...... hours pumping ...... gpm
Est. Yield ...... gpm: Well water was ...... ft. after ...... hours pumping ...... gpm
WELL WATER TO BE USED AS: 5 Public water supply 8 Air conditioning 11 Injection well
1 Domestic 3 Feedlot 6 Oil field water supply 9 Dewatering 12 Other (Specify below)
2 Irrigation 4 Industrial 7 Domestic (lawn & garden) 10 Monitoring well
Was a chemical/bacteriological sample submitted to Department? Yes ...... No ...... If yes, mo/day/yrs
Sample was submitted ...... Water well disinfected? Yes ...... No ......

5 TYPE OF CASING USED: 1 Steel 2 PVC 3 RMP (SR) 4 ABS 5 Wrought Iron 6 Asbestos-Cement 7 Fiberglass 8 Concrete tile 9 Other (specify below)
CASING JOINTS: Glued ...... Clamped ...... Welded ...... Threaded ......
Blank casing diameter ...... in. to ...... ft., Diameter ...... in. to ...... ft., Diameter ...... in. to ...... ft.
Casing height above land surface ...... in., weight ...... lbs./ft. Wall thickness or gauge No. ......
TYPE OF SCREEN OR PERFORATION MATERIAL:
1 Steel 3 Stainless Steel 5 Fiberglass 7 PVC 9 ABS 11 Other (Specify) ......
2 Brass 4 Galvanized Steel 6 Concrete tile 8 RM (SR) 10 Asbestos-Cement 12 None used (open hole)
SCREEN OR PERFORATION OPENINGS ARE:
1 Continuous slot 3 Mill slot 5 Gauzed wrapped 7 Torch cut 9 Drilled holes 11 None (open hole)
2 Louvered shutter 4 Key punched 6 Wire wrapped 8 Saw Cut 10 Other (Specify) ......
SCREEN-PERFORATED INTERVALS: From ...... ft. to ...... ft., From ...... ft. to ...... ft.
From ...... ft. to ...... ft., From ...... ft. to ...... ft.
GRAVEL PACK INTERVALS: From ...... ft. to ...... ft., From ...... ft. to ...... ft.
From ...... ft. to ...... ft., From ...... ft. to ...... ft.

6 GROUT MATERIAL: 1 Neat Cement 2 Cement grout 3 Bentonite 4 Other ......
Grout Intervals: From ...... ft. to ...... ft., From ...... ft. to ...... ft., From ...... ft. to ...... ft.
What is the nearest source of possible contamination:
1 Septic tank 4 Lateral lines 7 Pit privy 10 Livestock pens 13 Insecticide Storage 16 Other (specify below)
2 Sewer lines 5 Cess pool 8 Sewage lagoon 11 Fuel storage 14 Abandoned water well
3 Watertight sewer lines 6 Seepage pit 9 Feedyard 12 Fertilizer Storage 15 Oil well/gas well
Direction from well? ...... How many feet? ......

FROM	TO	LITHOLOGIC LOG	FROM	TO	PLUGGING INTERVALS
296	370	Clay, tan, brown, yellow, with some cemented sand, shale pieces, and caliche			
370	413	Clay, tan, brown, sandy, with caliche streaks			
413	433	Sand, gravel, fine to medium			
433	445	Weathered shale, yellow, black			
445	460	Clay, red, gray, white			

CONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was (1) constructed (2) reconstructed (3) plugged under my jurisdiction and was completed on (mo/day/year) 06-20-07 and this record is true to the best of my knowledge and belief.
Kansas Water Well Contractor's License No. 185 This Water Well Record was completed on (mo/day/year) 06-26-07
Under the business name of Clarke Well & Equipment, Inc. by (signature)

INSTRUCTIONS: Use typewriter or ball point pen. *PLEASE PRESS FIRMLY* and *PRINT* clearly. Please fill in blanks, underline or circle the correct answers. Send top three copies to Kansas Department of Health and Environment, Bureau of Water, Geology Section, 1000 SW Jackson St., Suite 420, Topeka, Kansas 66612-1367. Telephone 785-296-5522. Send one to WATER WELL OWNER and retain one for your records. Fee of $5.00 for each constructed well.

161 8726 Site #2 OBGMD-1

Corrected Copy
Form WWC-5

WATER WELL RECORD

Division of Water Resources; App. No.

1 LOCATION OF WATER WELL: County: Scott

Fraction: NE 1/4 NE 1/4 NE 1/4 | Section Number: 1 | Township Number: T 18 S | Range Number: R 33 E (W)

Distance and direction from nearest town or city street address of well if located within city? Approximately 2 1/2 miles north of Scott City

Global Positioning Systems (decimal degrees, min. of 4 digits)
Latitude: 38.52561
Longitude: -100.908705
Elevation: Unknown
Datum: NAD83
Data Collection Method: WAAS GPS Unit

2 WATER WELL OWNER: ~~University of Kansas Center for Research, Inc. 2385 Irving Hill Road Lawrence, KS 66045-7563~~ Kansas Geological Survey, 1930 Constant Ave., Lawrence, KS 66045
RR#, St. Address, Box #
City, State, ZIP Code

3 LOCATE WELL'S LOCATION WITH AN "X" IN SECTION BOX:

N
W --NW-- --NE-- (X) E
--SW-- --SE--
S

4 DEPTH OF COMPLETED WELL 227 ft.

Depth(s) Groundwater Encountered (1) 134.74' ft. (2) .... ft. (3) 08-21-07 ft.

WELL'S STATIC WATER LEVEL ~~213.37~~ ft. below land surface measured on mo/day/yr ~~07-10-07~~

Pump test data: Well water was Not checked ft. after .... hours pumping .... gpm

Est. Yield Unknown gpm: Well water was .... ft. after .... hours pumping .... gpm

WELL WATER TO BE USED AS: 5 Public water supply 8 Air conditioning 11 Injection well
1 Domestic 3 Feedlot 6 Oil field water supply 9 Dewatering (12) Other (Specify below)
2 Irrigation 4 Industrial 7 Domestic (lawn & garden) 10 Monitoring well — Observation

Was a chemical/bacteriological sample submitted to Department? Yes .... No ✓ If yes, mo/day/yrs

Sample was submitted .... Water well disinfected? Yes .... No ✓

5 TYPE OF CASING USED: 1 Steel 3 RMP (SR) 5 Wrought Iron 6 Asbestos-Cement 7 Fiberglass 8 Concrete tile 9 Other (specify below) (2) PVC 4 ABS

CASING JOINTS: Glued ✓ Clamped .... Welded .... Threaded ....

Blank casing diameter 2 1/2 in. to 215 ft., Diameter .... in. to .... ft., Diameter .... in. to .... ft.

Casing height above land surface 24 in., weight 1.10 lbs./ft. Wall thickness or gauge No. .203

TYPE OF SCREEN OR PERFORATION MATERIAL:
1 Steel 3 Stainless Steel 5 Fiberglass (7) PVC 9 ABS 11 Other (Specify)
2 Brass 4 Galvanized Steel 6 Concrete tile 8 RM (SR) 10 Asbestos-Cement 12 None used (open hole)

SCREEN OR PERFORATION OPENINGS ARE:
1 Continuous slot (3) Mill slot 5 Gauzed wrapped 7 Torch cut 9 Drilled holes 11 None (open hole)
2 Louvered shutter 4 Key punched 6 Wire wrapped 8 Saw Cut 10 Other (Specify)

SCREEN-PERFORATED INTERVALS: From 215 ft. to 225 ft., From .... ft. to .... ft.
From .... ft. to .... ft., From .... ft. to .... ft.

GRAVEL PACK INTERVALS: From 185 ft. to 232 ft., From .... ft. to .... ft.
From .... ft. to .... ft., From .... ft. to .... ft.

6 GROUT MATERIAL: (1) Neat Cement 2 Cement grout 3 Bentonite (4) Other Bentonite Holeplug

Grout Intervals: From 4 ft. to 185 ft., From .... ft. to .... ft., From 0 ft. to 4 ft.

What is the nearest source of possible contamination:
1 Septic tank 2 Sewer lines 3 Watertight sewer lines 4 Lateral lines 5 Cess pool 6 Seepage pit 7 Pit privy 8 Sewage lagoon 9 Feedyard 10 Livestock pens 11 Fuel storage 12 Fertilizer Storage 13 Insecticide Storage 14 Abandoned water well 15 Oil well/gas well (16) Other (specify below) None known

Direction from well? .... How many feet? ....

FROM	TO	LITHOLOGIC LOG	FROM	TO	PLUGGING INTERVALS
0	3	Topsoil	107	122	Sand and gravel, medium to fine
3	15	Clay, brown, silty, hard	122	131	Clay, tan and white, hard, silty, with streaks,
15	29	Clay, light gray, hard			cemented sand
29	38	Sand and gravel, medium to fine	131	133	Sand and gravel, medium to fine
38	47	Clay, gray, hard	133	135	Clay, brown, hard
47	71	Sand and gravel, coarse to fine	135	142	Cemented sand, hard, and clay, white
71	79	Clay, tan and white, hard	142	151	Sand and gravel, medium to fine
79	86	Sand and gravel, medium to fine, with clay	151	153	Cemented sand, hard
		streaks, tan	153	154	Sand and gravel, medium to fine, with clay
86	103	Clay, white, hard, with streaks, cemented sand			streaks, brown
103	107	Clay, tan and white, hard, silty	154	161	Clay, brown, hard, with gravel streaks

CONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was (1) (constructed) (2) reconstructed (3) plugged under my jurisdiction and was completed on (mo/day/year) 07-10-07 and this record is true to the best of my knowledge and belief.

Kansas Water Well Contractor's License No. 185 This Water Well Record was completed on (mo/day/year) 07-11-07

Under the business name of Clarke Well & Equipment, Inc. by (signature) [signature]

INSTRUCTIONS: Use typewriter or ball point pen. *PLEASE PRESS FIRMLY* and *PRINT* clearly. Please fill in blanks, underline or circle the correct answers. Send top three copies to Kansas Department of Health and Environment, Bureau of Water, Geology Section, 1000 SW Jackson St., Suite 420, Topeka, Kansas 66612-1367. Telephone 785-296-5522. Send one to WATER WELL OWNER and retain one for your records. Fee of $5.00 for each constructed well.

162 8726 Site #2 OBGMD-1 (Cont'd) **Corrected Copy**

WATER WELL RECORD Form WWC-5 Division of Water Resources; App. No.

1 LOCATION OF WATER WELL: County: Scott	Fraction NE 1/4 NE 1/4 NE 1/4	Section Number 1	Township Number T 18 S	Range Number R 33 E [✓ W]

Distance and direction from nearest town or city street address of well if located within city? Approximately 2 1/2 miles north of Scott City

Global Positioning Systems (decimal degrees, min. of 4 digits)
Latitude: 38.52561
Longitude: -100.908705
Elevation: Unknown
Datum: NAD83
Data Collection Method: WAAS GPS Unit

2 WATER WELL OWNER: ~~University of Kansas Center for Research, Inc 2385 Irving Hill Road Lawrence, KS 66045-7563~~ Kansas Geological Survey
RR#, St. Address, Box # : 1930 Constant Ave.
City, State, ZIP Code : Lawrence, KS 66045

3 LOCATE WELL'S LOCATION WITH AN "X" IN SECTION BOX:
N
--NW-- --NE-- X
W E
--SW-- --SE--
S

4 DEPTH OF COMPLETED WELL .... ft.
Depth(s) Groundwater Encountered (1) .... ft. (2) .... ft. (3) .... ft.
WELL'S STATIC WATER LEVEL .... ft. below land surface measured on mo/day/yr ....
Pump test data: Well water was .... ft. after .... hours pumping .... gpm
Est. Yield .... gpm: Well water was .... ft. after .... hours pumping .... gpm
WELL WATER TO BE USED AS: 5 Public water supply 8 Air conditioning 11 Injection well
1 Domestic 3 Feedlot 6 Oil field water supply 9 Dewatering 12 Other (Specify below)
2 Irrigation 4 Industrial 7 Domestic (lawn & garden) 10 Monitoring well
Was a chemical/bacteriological sample submitted to Department? Yes ...... No ...... If yes, mo/day/yrs
Sample was submitted .... Water well disinfected? Yes ...... No ......

5 TYPE OF CASING USED: 1 Steel 2 PVC 3 RMP (SR) 4 ABS 5 Wrought Iron 6 Asbestos-Cement 7 Fiberglass 8 Concrete tile 9 Other (specify below)
CASING JOINTS: Glued ...... Clamped ...... Welded ...... Threaded ......
Blank casing diameter ...... in. to ...... ft., Diameter ...... in. to ...... ft., Diameter ...... in. to ...... ft.
Casing height above land surface ...... in., weight ...... lbs./ft. Wall thickness or gauge No. ......

TYPE OF SCREEN OR PERFORATION MATERIAL:
1 Steel 3 Stainless Steel 5 Fiberglass 7 PVC 9 ABS 11 Other (Specify) ....
2 Brass 4 Galvanized Steel 6 Concrete tile 8 RM (SR) 10 Asbestos-Cement 12 None used (open hole)

SCREEN OR PERFORATION OPENINGS ARE:
1 Continuous slot 3 Mill slot 5 Gauzed wrapped 7 Torch cut 9 Drilled holes 11 None (open hole)
2 Louvered shutter 4 Key punched 6 Wire wrapped 8 Saw Cut 10 Other (Specify) ....

SCREEN-PERFORATED INTERVALS: From ...... ft. to ...... ft., From ...... ft. to ...... ft.
From ...... ft. to ...... ft., From ...... ft. to ...... ft.
GRAVEL PACK INTERVALS: From ...... ft. to ...... ft., From ...... ft. to ...... ft.
From ...... ft. to ...... ft., From ...... ft. to ...... ft.

6 GROUT MATERIAL: 1 Neat Cement 2 Cement grout 3 Bentonite 4 Other ....
Grout Intervals: From ...... ft. to ...... ft., From ...... ft. to ...... ft., From ...... ft. to ...... ft.

What is the nearest source of possible contamination:
1 Septic tank 2 Sewer lines 3 Watertight sewer lines 4 Lateral lines 5 Cess pool 6 Seepage pit 7 Pit privy 8 Sewage lagoon 9 Feedyard 10 Livestock pens 11 Fuel storage 12 Fertilizer Storage 13 Insecticide Storage 14 Abandoned water well 15 Oil well/gas well 16 Other (specify below) ....
Direction from well? .... How many feet? ....

FROM	TO	LITHOLOGIC LOG	FROM	TO	PLUGGING INTERVALS
161	174	Sand and gravel, medium to fine, cemented,			
		hard, with clay streaks, white			
174	196	Sand and gravel, coarse to fine			
196	213	Clay, white, hard, with gravel streaks			
213	218	Clay, tannish yellow, hard			
218	223	Sand and gravel, medium to fine			
223	228	Weathered shale, soft			
228	232	Shale, dark gray, hard			

CONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was (1) [✓ constructed] (2) reconstructed (3) plugged under my jurisdiction and was completed on (mo/day/year) 07-10-07 and this record is true to the best of my knowledge and belief. Kansas Water Well Contractor's License No. 185 This Water Well Record was completed on (mo/day/year) 07-11-07
Under the business name of Clarke Well & Equipment, Inc. by (signature) [illegible]

INSTRUCTIONS: Use typewriter or ball point pen. *PLEASE PRESS FIRMLY* and *PRINT* clearly. Please fill in blanks, underline or circle the correct answers. Send top three copies to Kansas Department of Health and Environment, Bureau of Water, Geology Section, 1000 SW Jackson St., Suite 420, Topeka, Kansas 66612-1367. Telephone 785-296-5522. Send one to WATER WELL OWNER and retain one for your records. Fee of $5.00 for each constructed well.

159 8726 Site #1 OBGMD-4

Corrected Copy

WATER WELL RECORD Form WWC-5

Division of Water Resources; App. No.

1 LOCATION OF WATER WELL: County: Thomas | Fraction: NW 1/4 NW 1/4 NW 1/4 | Section Number: 33 | Township Number: T 9 S | Range Number: R 33 E (W)

Distance and direction from nearest town or city street address of well if located within city? Approximately 7 miles north and 8 miles west of Oakley

Global Positioning Systems (decimal degrees, min. of 4 digits)
Latitude: 39.234506
Longitude: -101.018504
Elevation: Unknown
Datum: NAD83
Data Collection Method: WAAS GPS Unit

2 WATER WELL OWNER: ~~University of Kansas Center for Research, Inc. 2385 Irving Hill Road Lawrence, KS 66045-7563~~ Kansas Geological Survey 1930 Constant Ave. Lawrence, KS 66045
RR#, St. Address, Box #
City, State, ZIP Code

3 LOCATE WELL'S LOCATION WITH AN "X" IN SECTION BOX: N / W / E / S; --NW-- (x), --NE--, --SW--, --SE--

4 DEPTH OF COMPLETED WELL 286 ft.

Depth(s) Groundwater Encountered (1) ft. (2) ft. (3) ft.

WELL'S STATIC WATER LEVEL 213.67 ft. below land surface measured on mo/day/yr 07-03-07

Pump test data: Well water was Not checked ft. after hours pumping gpm

Est. Yield Unknown gpm: Well water was ft. after hours pumping gpm

WELL WATER TO BE USED AS: 5 Public water supply 8 Air conditioning 11 Injection well 1 Domestic 3 Feedlot 6 Oil field water supply 9 Dewatering (12) Other (Specify below) 2 Irrigation 4 Industrial 7 Domestic (lawn & garden) 10 Monitoring well — Observation

Was a chemical/bacteriological sample submitted to Department? Yes ___ No ✓ If yes, mo/day/yrs

Sample was submitted ___ Water well disinfected? Yes ___ No ✓

5 TYPE OF CASING USED: 1 Steel 3 RMP (SR) (2) PVC 4 ABS 5 Wrought Iron 6 Asbestos-Cement 7 Fiberglass 8 Concrete tile 9 Other (specify below)

CASING JOINTS: Glued ✓ Clamped ___ Welded ___ Threaded ___

Blank casing diameter 2 1/2 in. to 274 ft., Diameter ___ in. to ___ ft., Diameter ___ in. to ___ ft.

Casing height above land surface 24 in., weight 1.10 lbs./ft. Wall thickness or gauge No. .203

TYPE OF SCREEN OR PERFORATION MATERIAL: 1 Steel 3 Stainless Steel 5 Fiberglass (7) PVC 9 ABS 11 Other (Specify) 2 Brass 4 Galvanized Steel 6 Concrete tile 8 RM (SR) 10 Asbestos-Cement 12 None used (open hole)

SCREEN OR PERFORATION OPENINGS ARE: 1 Continuous slot (3) Mill slot 5 Gauzed wrapped 7 Torch cut 9 Drilled holes 11 None (open hole) 2 Louvered shutter 4 Key punched 6 Wire wrapped 8 Saw Cut 10 Other (Specify)

SCREEN-PERFORATED INTERVALS: From 274 ft. to 284 ft., From ___ ft. to ___ ft.
From ___ ft. to ___ ft., From ___ ft. to ___ ft.

GRAVEL PACK INTERVALS: From 250 ft. to 284 ft., From ___ ft. to ___ ft.
From ___ ft. to ___ ft., From ___ ft. to ___ ft.

6 GROUT MATERIAL: (1) Neat Cement 2 Cement grout 3 Bentonite (4) Other Bentonite Holeplug

Grout Intervals: From 4 ft. to 25 ft., From ___ ft. to ___ ft., From 0 ft. to 4 ft.

What is the nearest source of possible contamination: 1 Septic tank 2 Sewer lines 3 Watertight sewer lines 4 Lateral lines 5 Cess pool 6 Seepage pit 7 Pit privy 8 Sewage lagoon 9 Feedyard 10 Livestock pens 11 Fuel storage 12 Fertilizer Storage 13 Insecticide Storage 14 Abandoned water well 15 Oil well/gas well (16) Other (specify below) None known

Direction from well? ___ How many feet? ___

FROM	TO	LITHOLOGIC LOG	FROM	TO	PLUGGING INTERVALS
0	3	Topsoil	157	161	Sand and gravel, coarse to fine, with streaks
3	7	Clay, dark gray, hard			cemented sand
7	37	Clay, tan, soft, silty	161	169	Clay, brown, sandy, hard
37	51	Clay, white, sandy, hard	169	176	Cemented sand, hard
51	62	Clay, tannish white, hard, with gravel streaks,	176	201	Sand and gravel, coarse to fine, table chatter
		medium to fine	201	211	Clay, tan, hard, with streaks, sand and
62	103	Sand and gravel, coarse to fine, table chatter			gravel, 50/50 mix
103	129	Clay, reddish brown, sandy, with gravel	211	217	Clay, white, hard, sandy
		streaks	217	260	Sand and gravel, medium to fine, with clay
129	145	Sand and gravel, medium to fine			streaks, white
145	157	Clay, tan, hard			

CONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was (1) (constructed) (2) reconstructed (3) plugged under my jurisdiction and was completed on (mo/day/year) 07-03-07 and this record is true to the best of my knowledge and belief. Kansas Water Well Contractor's License No. 185 This Water Well Record was completed on (mo/day/year) 07-10-07

Under the business name of Clarke Well & Equipment, Inc. by (signature) [signature]

INSTRUCTIONS: Use typewriter or ball point pen. PLEASE PRESS FIRMLY and PRINT clearly. Please fill in blanks, underline or circle the correct answers. Send top three copies to Kansas Department of Health and Environment, Bureau of Water, Geology Section, 1000 SW Jackson St., Suite 420, Topeka, Kansas 66612-1367. Telephone 785-296-5522. Send one to WATER WELL OWNER and retain one for your records. Fee of $5.00 for each constructed well.

160 8726 Site #1 OBGMD-4 (Cont'd) **Corrected Copy**

WATER WELL RECORD Form WWC-5 Division of Water Resources; App. No.

1 LOCATION OF WATER WELL: County: Thomas	Fraction NW 1/4 NW 1/4 NW 1/4	Section Number 33	Township Number T 9 S	Range Number R 33 E (W)

Distance and direction from nearest town or city street address of well if located within city? Approximately 8 miles west and 7 miles north of Oakley

Global Positioning Systems (decimal degrees, min. of 4 digits)
Latitude: 39.234506
Longitude: -101.018504
Elevation: Unknown
Datum: NAD83
Data Collection Method: WAAS GPS Unit

2 WATER WELL OWNER: ~~University of Kansas Center for Research, Inc. 2385 Irving Hill Road Lawrence, KS 66045-7563~~ Kansas Geological Survey 1930 Constant Ave. Lawrence, KS 66045
RR#, St. Address, Box #
City, State, ZIP Code

3 LOCATE WELL'S LOCATION WITH AN "X" IN SECTION BOX: N, W, E, S; --NW-- (x), --NE--, --SW--, --SE--

4 DEPTH OF COMPLETED WELL .... ft.
Depth(s) Groundwater Encountered (1) .... ft. (2) .... ft. (3) .... ft.
WELL'S STATIC WATER LEVEL .... ft. below land surface measured on mo/day/yr ....
Pump test data: Well water was .... ft. after .... hours pumping .... gpm
Est. Yield .... gpm: Well water was .... ft. after .... hours pumping .... gpm
WELL WATER TO BE USED AS: 1 Domestic 2 Irrigation 3 Feedlot 4 Industrial 5 Public water supply 6 Oil field water supply 7 Domestic (lawn & garden) 8 Air conditioning 9 Dewatering 10 Monitoring well 11 Injection well 12 Other (Specify below)
Was a chemical/bacteriological sample submitted to Department? Yes .... No .... If yes, mo/day/yrs Sample was submitted .... Water well disinfected? Yes .... No ....

5 TYPE OF CASING USED: 1 Steel 2 PVC 3 RMP (SR) 4 ABS 5 Wrought Iron 6 Asbestos-Cement 7 Fiberglass 8 Concrete tile 9 Other (specify below)
CASING JOINTS: Glued .... Clamped .... Welded .... Threaded ....
Blank casing diameter .... in. to .... ft., Diameter .... in. to .... ft., Diameter .... in. to .... ft.
Casing height above land surface .... in., weight .... lbs./ft. Wall thickness or gauge No. ....
TYPE OF SCREEN OR PERFORATION MATERIAL: 1 Steel 2 Brass 3 Stainless Steel 4 Galvanized Steel 5 Fiberglass 6 Concrete tile 7 PVC 8 RM (SR) 9 ABS 10 Asbestos-Cement 11 Other (Specify) 12 None used (open hole)
SCREEN OR PERFORATION OPENINGS ARE: 1 Continuous slot 2 Louvered shutter 3 Mill slot 4 Key punched 5 Gauzed wrapped 6 Wire wrapped 7 Torch cut 8 Saw Cut 9 Drilled holes 10 Other (Specify) 11 None (open hole)
SCREEN-PERFORATED INTERVALS: From .... ft. to .... ft., From .... ft. to .... ft.
From .... ft. to .... ft., From .... ft. to .... ft.
GRAVEL PACK INTERVALS: From .... ft. to .... ft., From .... ft. to .... ft.
From .... ft. to .... ft., From .... ft. to .... ft.

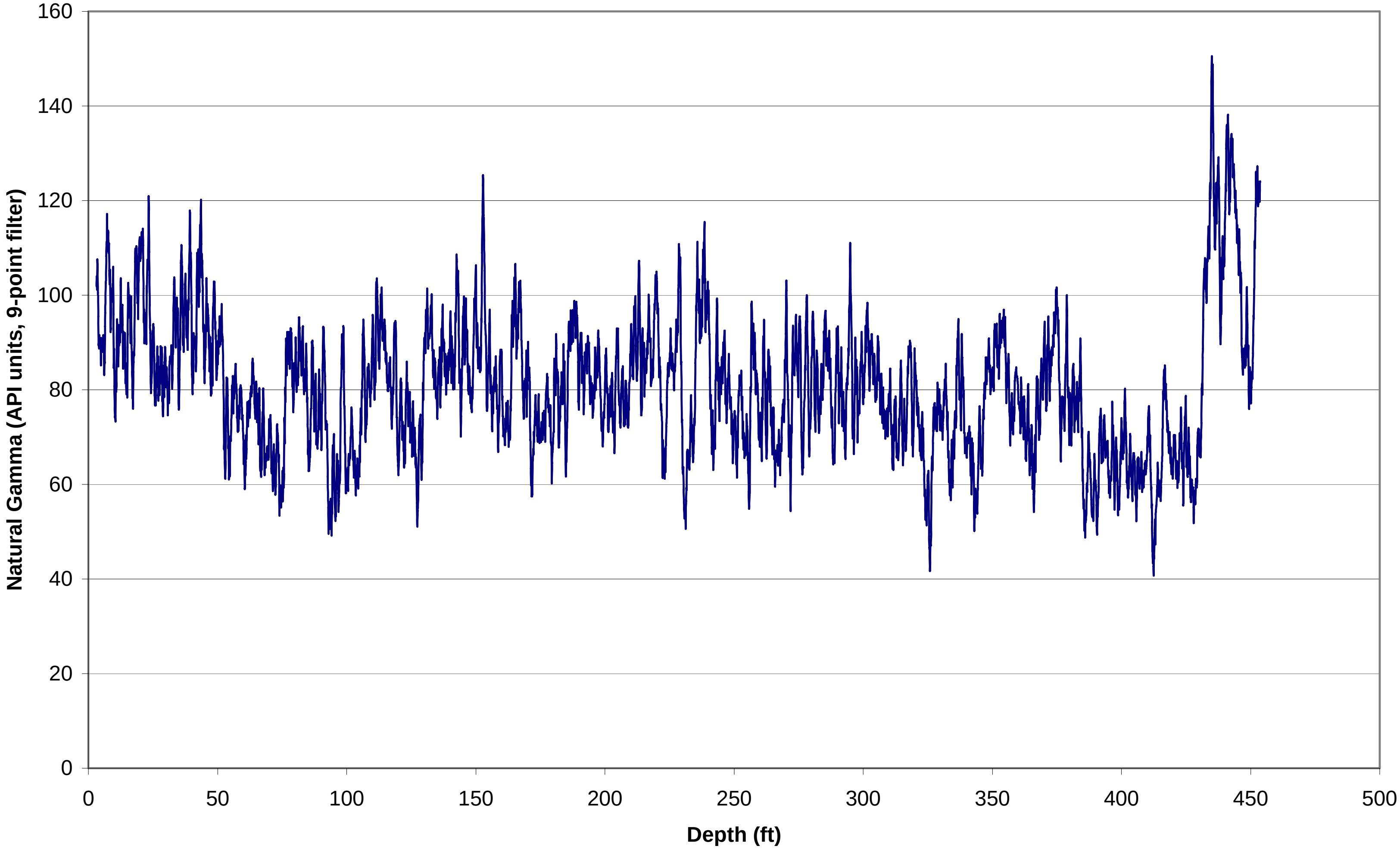
6 GROUT MATERIAL: 1 Neat Cement 2 Cement grout 3 Bentonite 4 Other ....
Grout Intervals: From .... ft. to .... ft., From .... ft. to .... ft., From .... ft. to .... ft.
What is the nearest source of possible contamination: 1 Septic tank 2 Sewer lines 3 Watertight sewer lines 4 Lateral lines 5 Cess pool 6 Seepage pit 7 Pit privy 8 Sewage lagoon 9 Feedyard 10 Livestock pens 11 Fuel storage 12 Fertilizer Storage 13 Insecticide Storage 14 Abandoned water well 15 Oil well/gas well 16 Other (specify below)
Direction from well? .... How many feet? ....

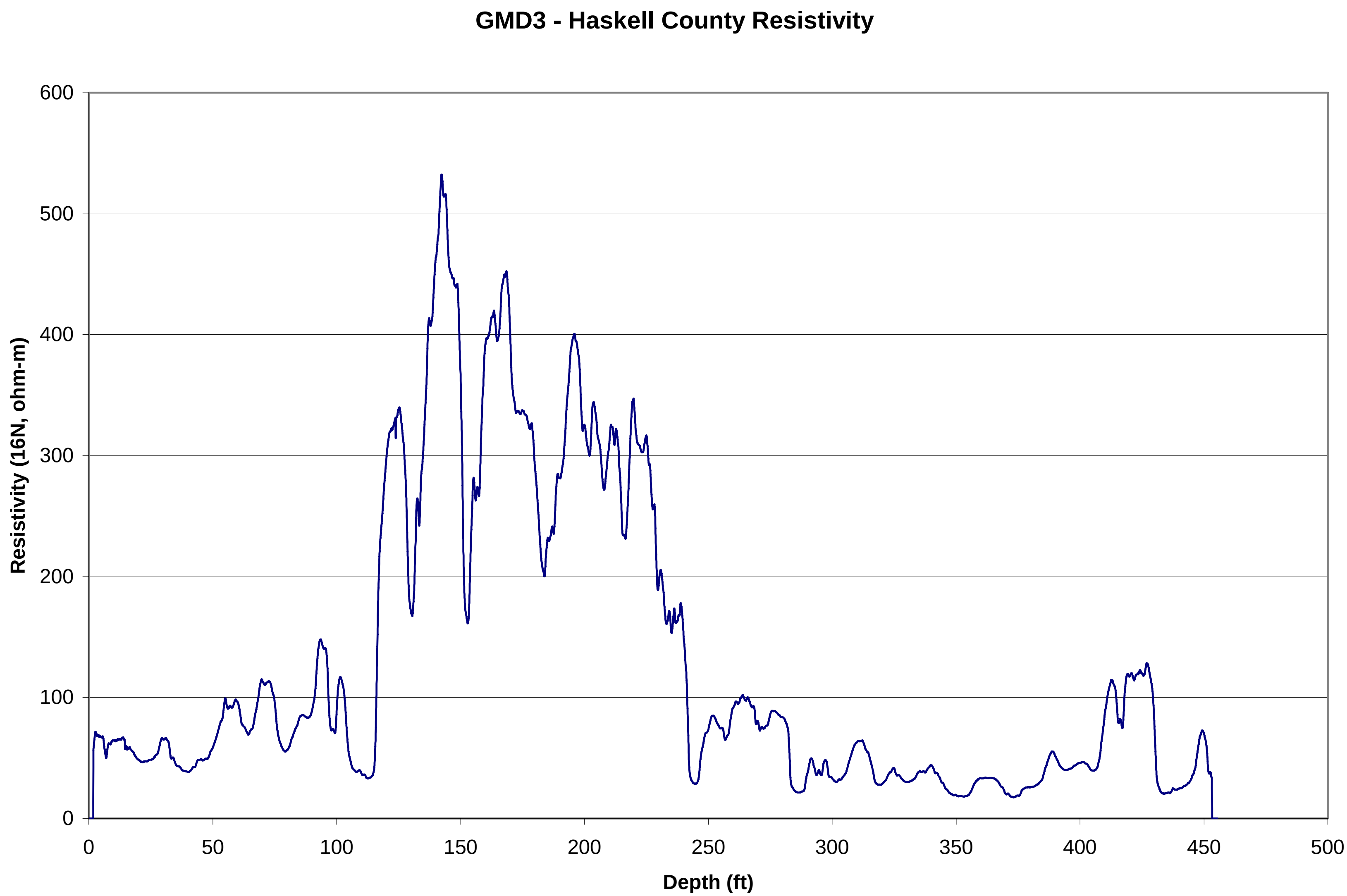
FROM	TO	LITHOLOGIC LOG	FROM	TO	PLUGGING INTERVALS
260	270	Clay, tan, hard, with gravel streaks, medium to fine, 50/50 mix			
270	272	Cemented sand, with clay streaks			
272	284	Clay, tan, hard, with sand and gravel, medium to fine, 50/50 mix			
284	294	Shale, weathered, green, gray, hard			

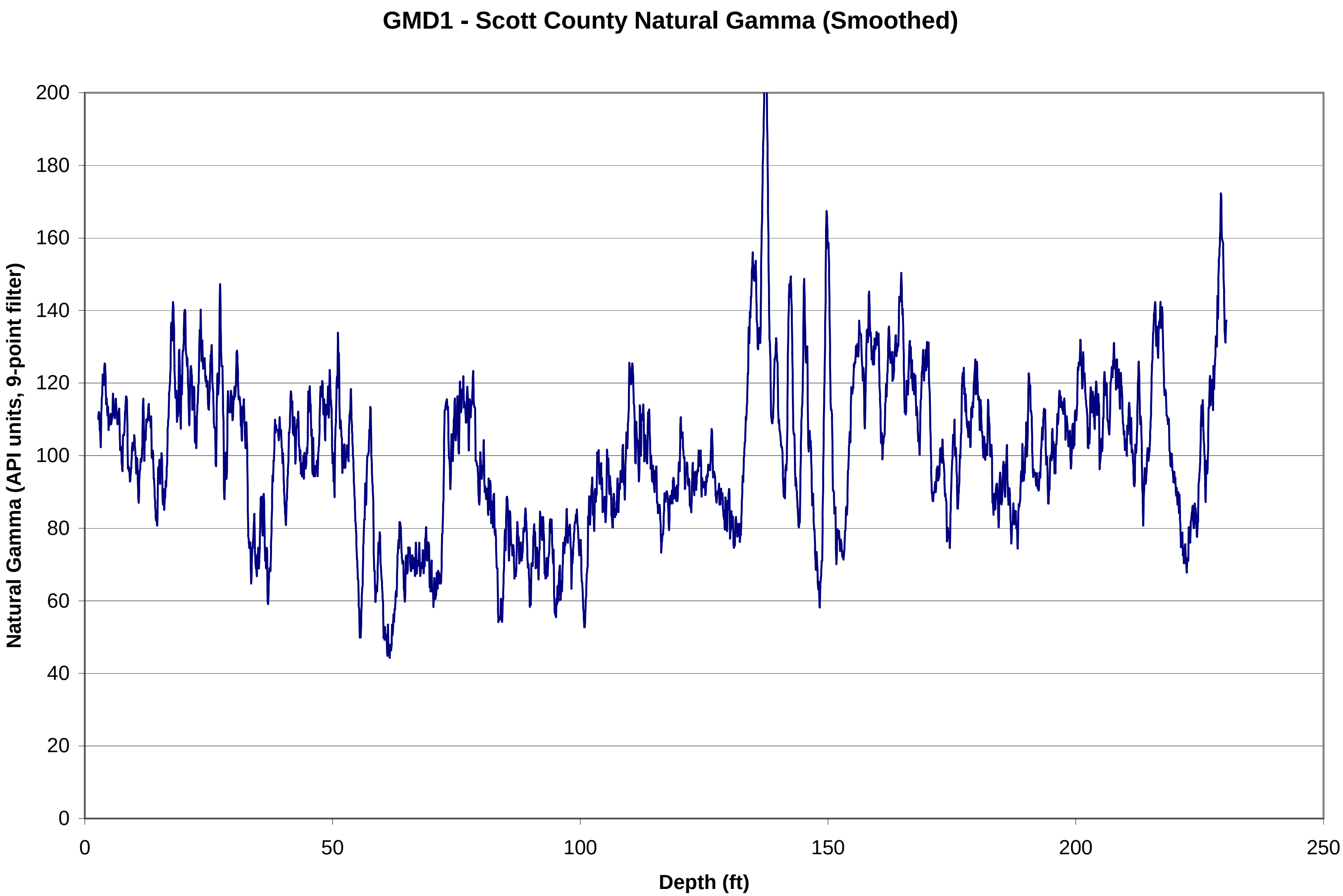
7 CONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was (1) (constructed) (2) reconstructed (3) plugged under my jurisdiction and was completed on (mo/day/year) 07-03-07 and this record is true to the best of my knowledge and belief. Kansas Water Well Contractor's License No. 185 This Water Well Record was completed on (mo/day/year) 07-10-07 Under the business name of Clarke Well & Equipment, Inc. by (signature) [signature]

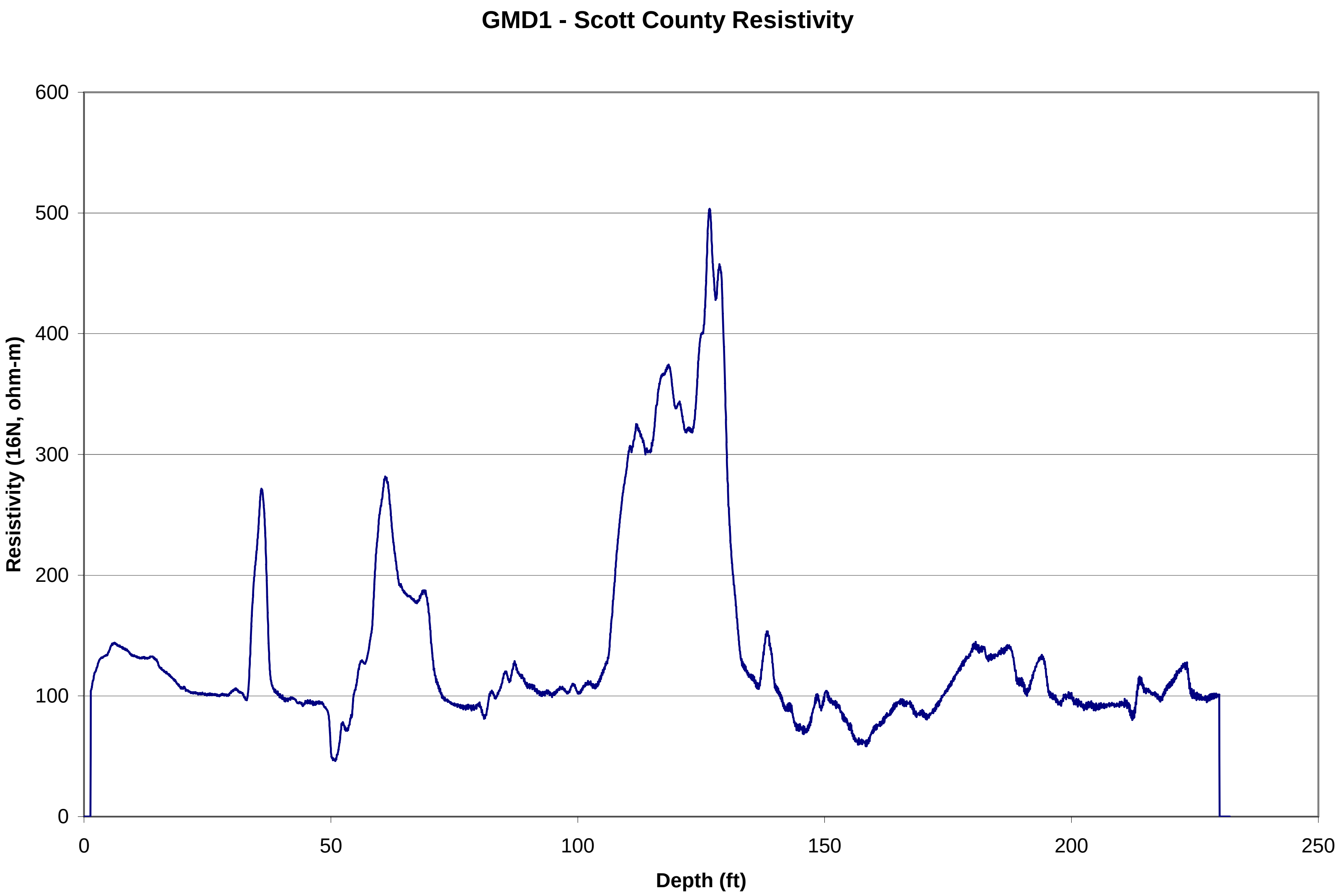
INSTRUCTIONS: Use typewriter or ball point pen. PLEASE PRESS FIRMLY and PRINT clearly. Please fill in blanks, underline or circle the correct answers. Send top three copies to Kansas Department of Health and Environment, Bureau of Water, Geology Section, 1000 SW Jackson St., Suite 420, Topeka, Kansas 66612-1367. Telephone 785-296-5522. Send one to WATER WELL OWNER and retain one for your records. Fee of $5.00 for each constructed well.

GMD3 - Haskell County Natural Gamma (Smoothed)

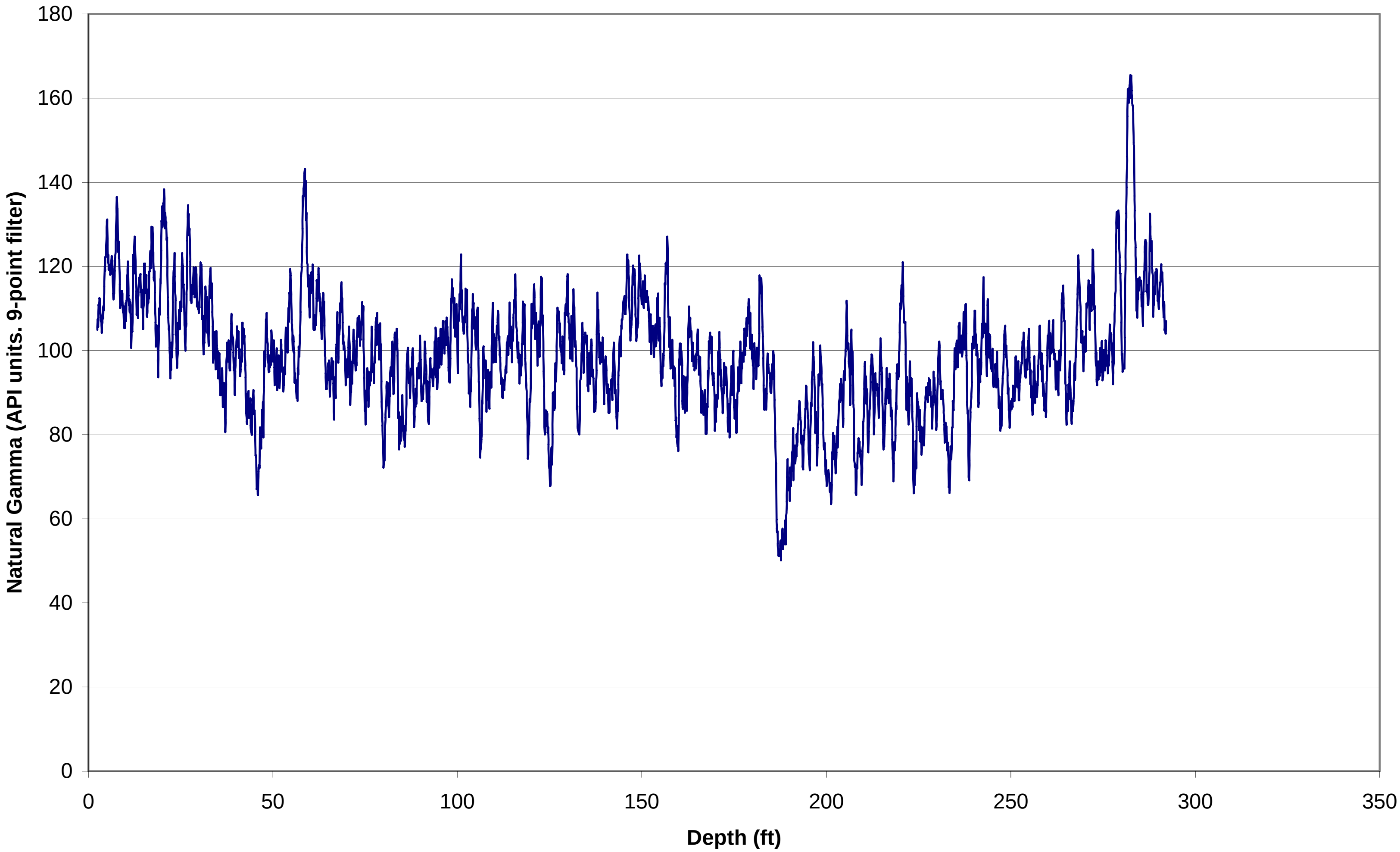


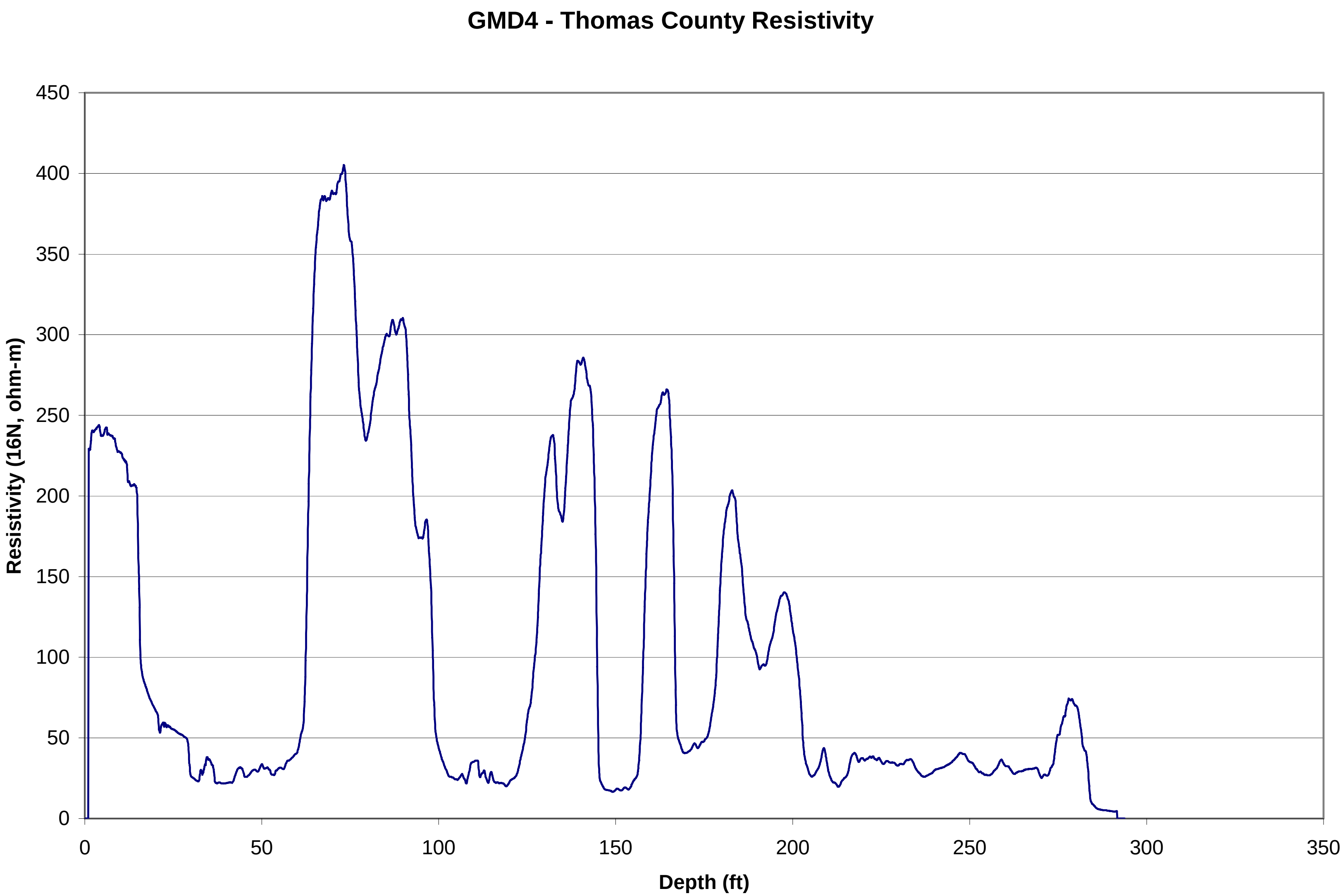

GMD3 - Haskell County Resistivity
Resistivity (16N, ohm-m)
0
100
200
300
400
500
600
Depth (ft)
0
50
100
150
200
250
300
350
400
450
500


GMD1 - Scott County Natural Gamma (Smoothed)
Natural Gamma (API units, 9-point filter)
Depth (ft)
0
20
40
60
80
100
120
140
160
180
200
0
50
100
150
200
250


GMD1 - Scott County Resistivity
Resistivity (16N, ohm-m)
600
500
400
300
200
100
0
0
50
100
150
200
250
Depth (ft)

GMD4 - Thomas County Natural Gamma (Smoothed)




GMD4 - Thomas County Resistivity
Resistivity (16N, ohm-m)
0
50
100
150
200
250
300
350
400
450
Depth (ft)
0
50
100
150
200
250
300
350